THE PSYCHOLOGY OF TIME AND ITS PHILOSOPHICAL IMPLICATIONS

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ABSTRACT OF THE DISSERTATION

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This dissertation offers new proposals, based on a philosophical appraisal of scientific findings, to address old philosophical problems regarding our immediate acquaintance with time. It focuses on two topics: our capacity to determine the length of intervals and our acquaintance with the present moment. A review of the relevant scientific findings concerning these topics grounds the main contributions of this dissertation. Thus, this study introduces to the philosophical literature an empirically adequate way to talk about how the mind represents time at the most fundamental level.

In order to account for our immediate acquaintance with the duration of intervals, a theoretical framework for classifying clocks is used to explain why the representational outputs of the circadian clock and the stopwatch have metric structure. A philosophical analysis of these outputs is proposed to classify them and explain their properties. With respect to our immediate acquaintance with the present, a novel two-phase model of the present is proposed. This model shows that there are two forms of acquaintance with the present, which has consequences for contemporary debates in the philosophy of time.

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I first started thinking about the topic of this dissertation because of conversations with Zenon Pylyshyn, whose work has heavily influenced the way in which I think about issues in the philosophy of mind. My interest in timing-mechanisms and metric representation greatly increased because of conversations with Rochel Gelman, Fuat Balci and Harry Haladjian. I am very grateful to all of them.

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List of abbreviations (In Alphabetical Order)

A-O: Action-Outcome Associations

CMIP: Cross-Modal Integration Processor

DMM: Direct Metasemantic Mechanism

IS: Intuitive Strength (of the A-theory)

OR: Openness and Retentiveness

PB: Phenomenal Binding

PS: Periodic Segmentation

PSP: Phenomenal Specious Present

RA: Representational Advantage Argument

RAA: Representational Advantage of the A-theory Argument

SBF: Striatal Beat Frequency Model

SC: Stream of Consciousness

SCN: Suprachiasmatic Nucleus

SP: Scientific Plausibility (of the A-theory)

S-R: Stimulus Response Associations

SSP: Sensorial Specious Present

TH: Truly Hybrid

TMD: Temporal Mental Demonstrative

TPMP: Two-Phase Model of the Present

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Introduction

Our awareness of time permeates our lives. It is so familiar to us that we take it for granted. It is always there in our decisions and actions. It accompanies our emotions, struggles and pleasant or unpleasant experiences. Our awareness of time is, metaphorically speaking, a constant companion. Not only humans, but also animals seem to be immediately acquainted with time because they are able to effortlessly calculate intervals and perform time sensitive tasks with great accuracy.

With the development of ever more precise clocks and techniques for measuring time we have become much better at representing and calculating time. Technology has had a significant impact on the way in which time dictates the rhythms of our lives. Scientific and cultural representations of time are more complex than ever before and this has made possible the intricate web of synchronized interactions that are characteristic of our times.

But how does the *mind* represent time? How should one characterize our awareness of time, which is the origin of other, more complex representations of time? Until very recently, these questions needed to be answered only by intuitive insight and philosophical analysis. Theses about how the mind represents time were offered by philosophers, which I will assess in this dissertation. But no evidence in support of these theses was available.

The psychology of time—particularly the study of how the mind estimates the duration of intervals and is acquainted with the present—has become a very important area of research in cognitive science. Experiments with animals that are very precise in time-sensitive tasks have produced valuable evidence, which shows that there are mechanisms for representing time and that the representations produced by these mechanisms have a structure that allows them to be combined with other representations, such as spatial representations.

Techniques for detecting brain activity have been used to correlate areas of the brain with time-representation functions. Psychologists have proposed models that identify the main computational processes underlying temporal representation and the psychological literature on timing mechanisms keeps growing. Thus, a vast array of findings is now available to verify or refute philosophical theses concerning our immediate awareness of time.

The scientific findings on which this dissertation focuses concern two clocks (the circadian clock and the stopwatch) and what psychologists call ‘simultaneity windows.’ These are extremely interesting findings that have not been carefully examined in the philosophical literature. The findings on the clocks show that the brain represents time by means of mechanisms that work in very much the same way as the clocks humans have designed. And the findings on simultaneity windows reveal that there are different ways of being acquainted with the present.

These findings have surprising and important consequences for philosophy. I hope that the philosophical theses offered in this dissertation will demonstrate that the combination of psychological research with philosophical analysis can be fruitful and produce general and consistent accounts of fundamental aspects of the mind, such as how it represents time.

Chapter 1

Minding Time

1.1. Introduction

Our awareness of time is a fundamental aspect of our lives and yet, explaining how exactly the human mind is aware of time is a problem that has puzzled philosophers and scientists for millennia. Aristotle asked whether time would exist without a mind that could *count* or *measure* time. (Aristotle, 1980, IV, 14) Augustine famously said: "It is in my own mind […] that I measure time. I must not allow my mind to insist that time is something objective." (Augustine, XI.27) Other philosophers, most notably Kant, have claimed that there is an inner *sense* of time. (Kant, 2000, 162-163)

These claims are very controversial from a metaphysical point of view. However, they capture the intuitive notion that in our daily experience we sense, measure or "count" time. But how could one explain these capacities for sensing time? How is it that we represent and experience time: what mechanisms are involved in time representation at the most fundamental level, such that they make possible our immediate acquaintance with time, and how should the representations of time that constitute what we intuitively call 'our immediate awareness of time' be characterized?

These are pressing questions that require empirical evidence and careful philosophical analysis. One can appreciate the importance of these issues by reviewing the contemporary literature on the philosophy of time, in which similar worries arise. More specifically, there are views on time which hold that while some properties of time, such as its ordered and asymmetric structure, are mind-independent, some of its other properties, such as its continuous "passage" or flow, supervene on our cognitive capacities. At the deflationary end of the spectrum of possible views is the claim that no aspects of time are mind-independent and thus that time itself is entirely supervenient on our cognitive capacities.

One may think that this extremely deflationary view (i.e., that there is no physical time) is extremely implausible. But actually, some physicists like Julian Barbour (2000) think that time should be "removed" from physics. Proponents of the complete elimination of time argue that such apparently drastic maneuver is actually compatible with physical theory. Obviously, postulating the inexistence of time poses the significant challenge of explaining *what is it* that we call 'time'? Barbour writes,

> No doubt many people will dismiss the suggestion that time may not exist as nonsense. I am not denying the powerful phenomenon we call time. But is it what it seems to be? After all, the Earth seems to be flat. I believe the true phenomenon is so different that, presented to you as I think it is without any mention of the word 'time', it would not occur to you to call it that. If time is removed from the foundations of physics, we shall not all suddenly feel that the flow of time has ceased. On the contrary, new timeless principles will explain why we *do* feel that time flows. (Barbour, 2000, 14)

Indeed, it seems as if time passes. We *do* feel time passing or more precisely, we are immediately acquainted with the duration of events. But if time does not exist, what could possibly explain our acquaintance with time? In the philosophical literature J. J. C. Smart, along with many philosophers of time called the 'B-theorists' take a somewhat less extreme view, arguing that only the feature of the flow or passage of time (i.e., that events are first future, then present and then past) is illusory, but that other features of time, such as the concatenation of events by the relations 'earlier' or 'at the same time' is real. However, the challenge remains: how to explain our acquaintance with the duration of events that gives rise to the sense of time flowing? Smart is aware of this challenge, and acknowledges that merely pointing out that the passage of time is an illusion is not enough:

> If the passage of time is an illusion it is a strange and intellectually worrying one. It would be good if we could not only give reasons for thinking that it *is* an illusion […] but also if we could give some sort of explanation of how this illusion arises. (Smart, 1980, 10)

I agree with Smart that an explanation of the cognitive basis of our immediate acquaintance with duration and the passage of time is badly needed in the philosophy of time literature. But, unlike Smart, I will be non-committal as to whether or not the so-called passage of time is a property *of time*. The psychology of time is challenging enough, and considerations about what time *is* are beyond the scope of this dissertation.

Views like those expressed by Barbour and Smart reveal the need for explaining the cognitive basis of temporal representation. The central role that cognitive capacities for representing time play in reductive accounts of the metaphysics of time (or of features of time) demands a serious effort by philosophers to "come to grips" with the scientific evidence on time cognition. Philosophers have made tentative empirical claims about time cognition, but very few have taken into account current scientific evidence and (as far as I know) none of them has *thoroughly* reviewed the scientific literature on time representation.[1] Take for instance the following set of claims by Smart:

> We are aware of the flow of information through our short-term memories and we confuse this with a flow of time itself. This conjecture is perhaps supported by empirical evidence according to which the greater the number of stimuli that there are in a given temporal interval the greater is the subjective estimate of the length of that

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[1] The last attempt at giving some kind of empirical account of time cognition in the philosophical literature was offered by R. Le Poidevin (2004a, 2007). However, the psychological evidence he mentions is not properly assessed and his account of time representation dismisses important psychological findings. Actually, his entire approach to this topic is quite aprioristic. For a criticism of Le Poidevin's account of time cognition along these lines see Callender, C. (2008b).

> interval. It might be further supported by some more equivocal evidence which suggest that the estimation of the length of an interval depends in the same way on the complexity of the stimuli. (Smart, 1980, 13)

Smart does not give any detail about the evidence he is relying upon. He says that his conjecture is *perhaps* supported by the empirical evidence that he hastily mentions. It is unclear what he means by 'equivocal evidence.' The connection he makes between the flow of information and the flow of time is extremely uninformative: there are several types of short-term memory, so it is unclear what specific mechanism and set of findings he might be referring to. And more importantly, whatever findings Smart has in mind, they are not the *relevant* psychological findings on time cognition (as I explain in chapters 2 and 3, the relevant findings on the representation of the length of intervals concern two cognitive clocks).

Therefore, Smart is not addressing the psychological evidence in a serious and systematic fashion. And unfortunately, there is no systematic account of the relevant psychological findings on time cognition in the philosophical literature. An important goal of this dissertation is to solve this problem by providing a systematic and thorough philosophical account of the psychological findings on time representation.

Another problem with philosophical accounts of time cognition is that they assume that the sense of time passing is the most critical psychological datum to be explained. However, the 'flow' or 'passage' metaphor is not unambiguous, so it is problematic to pinpoint what the datum is. What exactly is this representation or experience supposed to be and how should it be construed? What is our immediate awareness of time? Are there different forms of representing (and being aware of) time?

For instance, we are immediately aware of the duration of intervals and a key feature of our lives is that we can tell how long intervals are. Our capacity to represent the duration of experiences and actions frames our interaction with the world. This cognitive capacity to represent duration must be critical to explain the so-called "feeling" or experience that time flows. But how do we represent duration? By means of which mechanism(s) are we acquainted with duration? I address these questions in chapters 2 and 3.

There is another aspect of our immediate awareness of time. We seem to be immediately acquainted with the present. Bertrand Russell argued that we experience succession (that we perceive successive events) within the *specious present* (an extended moment of time that we experience as the present moment). Russell also said that we must be immediately acquainted with very recent past objects through "immediate memory." (Russell, B., 1913, 70) This also seems to be relevant to the so-called 'flow of time', but how should we determine if Russell is right? Are there findings that could explain our acquaintance with the present moment and confirm or disconfirm these claims by Russell (as well as similar claims by other philosophers)? I address these questions in chapter 4.

An explanation of these fundamental and primitive forms of time representation, informed by a serious assessment of the relevant psychological findings, is something that the philosophical literature is still missing. Given the amount of psychological evidence that can shed light on these issues, I propose it is time to do this right, i.e., it is time these old philosophical questions are answered based on a detailed assessment of the philosophical implications of current scientific findings, which should be carefully reviewed and interpreted, rather than hastily mentioned.

The two main topics of this dissertation are these basic ways of representing time: our immediate acquaintance with duration and with the present moment.[2] As mentioned, chapters 2 and 3 address our capacity to represent the duration of intervals and chapter 4 tackles the issue of the specious present. In chapter 5, I explain how my account of time representation has implications for debates on the metaphysics of time that appeal to our immediate acquaintance with the present. Throughout my dissertation, I examine the scientific evidence in detail, with the goal of providing a philosophical appraisal of scientific findings that could serve as a basis for philosophical debates on time representation.

Thus, I aim to achieve, with respect to the topic of temporal representation, what C. L. Hardin's (1988) *Color for Philosophers* accomplished with respect to the literature on color. Hardin's book introduced important scientific findings to the philosophical literature, thereby reshaping philosophical debates on color in a productive and scientifically informed fashion. Hardin says,

> I have wanted to encourage and provoke other philosophers to come to grips with the relevant scientific material, and to promulgate within the philosophical community the opinion that, henceforth, discussions about color proceeding in ignorance of visual science are intellectually irresponsible. (Hardin, 1988, xvi)

In earlier periods, philosophers paid little attention to the science of color. But when

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[2] Since these are the primitive representations of time that can be clearly defined and for which there is scientific evidence, I shall focus on the representation of the duration of intervals and our acquaintance with the present, and not on the more problematic notion of 'flow.' In the conclusion of chapters 4 and 5 I suggest that if there were an experience of the flow of time, it would depend on these two primitive representations. Thus, the

science started answering philosophical questions with experimental evidence, ignoring such findings in philosophical debates about color was no longer responsible. I suggest that something similar might happen with respect to the topic of the representation of time. This has already happened with respect to the *metaphysics* of time. Actually, a classic example of how science informed metaphysics is the way in which Einstein's theory of relativity transformed how metaphysicians approach topics related to the nature of spacetime.

But scientific findings do not come exclusively from the natural sciences. An increasing number of experiments in cognitive science that directly address questions about time representation should, like other scientific findings, inform philosophical debates. Hardin's work is a clear example of how introducing scientific findings reshaped philosophical debates about color. Hopefully my dissertation will have a similar impact with respect to philosophical debates on temporal representation.

I shall emphasize two issues concerning the scope of this dissertation. First, I shall focus on the *representation* of time and not on the nature of time or what time *is*. Some of my proposals on time representation have implications for debates in the metaphysics of time that appeal to our immediate acquaintance with the present, and I will explain them in chapter 5. But the issue of what is the nature of time is beyond the scope of the present study.

Second, I focus only on the *sensory-motor representation* of time, i.e., only on those mechanisms and representations that could explain our *immediate* acquaintance with time, or the most fundamental forms of time representation that ground other mental

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only way to talk sensibly about the flow of time at the sensory-motor level is in terms of representations of time, such as cultural, linguistic or scientific representations of time. In the next section, I spell out in more detail the primitive nature of the sensory-motor representations that I examine in the reminder of my dissertation and in section 1.3, I describe its original contributions.

1.2. Time: the most primitive representation

Of all the experiences and representations that constitute our awareness and sensory-motor apprehension of features of the world, our immediate representation of time (a type of temporal representation that grounds other representations of time and does not depend on other representations) is unique because it seems to be the most primitive or fundamental. As Ernst Mach noticed in *The Analysis of Sensations*:

> Much more difficult than the investigation of space-sensation is that of time-sensation. Many sensations make their appearance with, others without, a clear sensation of space. But time-sensation accompanies every other sensation, and can be wholly separated from none. (Mach, 1959, 245)[3]

How could one make more precise the point that Mach is trying to make? An area of philosophical research in which the issue of the primitiveness of representations is frequently discussed is the philosophy of perception. An essential assumption of any philosophical theory of perception is that there are space-time coordinates that serve as the basis of sensory-motor identifications. This issue comes up vividly in debates about a difficulty concerning the perception of features co-instantiated in a perceptual object, called the 'binding problem.'

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the representations and mechanisms that I assess in the following chapters.

[3] Hans Reichenbach makes a similar remark: "The experience of time is allotted a primary position among conscious experiences and is felt as more immediate than the experience of space. There is indeed no experience of space in the direct sense in which we feel the flow of time during our life." (Reichenbach, 1958,110)

The problem can be succinctly captured by the question: how does the sensory-motor system binds or “puts together” different features that are processed independently (such as color and shape in the case of vision) in order to build a unified representation of an object with a specific color and shape? The most influential solution to this problem postulates that space-time coordinates serve as the *referents* that the sensory-motor system uses to attribute features and represent objects and their properties. Austen Clark (2000) suggests that the capacity of the sensory-motor system to solve the binging problem based on spatiotemporal coordination might be the *cognitive origin* of the most fundamental linguistic distinction, i.e., the subject-predicate distinction:

> If in fact similar collecting principles apply to pairings of place-times and features as to subjects and predicates, then the two phenomena may be related to one another, and the linguistic phenomena of reference and predication may have ancestors in our sensory systems. Nature tends to copy solutions that work, and if aeons ago the ancestors of our visual system (for example) managed to solve the Many Properties problem, it would not be entirely surprising to find that later linguistic systems simply copied their solution. If this were so, then the distinction between reference and predication reflects an even deeper and older architectural feature of the neural organization of our sensory systems. (Clark, 2000, 73-74)

I am not endorsing Clark’s conjecture about the origin of the linguistic distinction between subject and predicate (although it is plausible), nor am I interested in the binding problem per se. What I want to emphasize is the primitive character of sensory-motor spatiotemporal coordination. Clark nicely captures this idea when he explains how without spatiotemporal coordinates perceptual representation would not get off the ground because no attribution of features to sensorial referents (place-times) would be possible.[4]

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[4] See Clark (2000), particularly section 5.

Spatiotemporal coordinates are essential for the sensory-motor system to make sense of the features it registers and interpret them as objects of perception. It is exactly this characteristic of our immediate representations of time (i.e., that they are *essential* to interpret sensorial stimuli) that makes them primitive and fundamental. Without these primitive representations of time and their coordination with spatial information, the identification of perceptual objects would be impossible.

Mach's point can now be made more precisely. Space and time representation are fundamental to identify objects at the sensory-motor level, but time representation is *even more* fundamental because we can have sensorial representations that are not spatial in character (i.e., they seem to have temporal, but not spatial coordinates). Think of an experience of "pure expectation." It seems that when you are expecting something to happen but you do not know exactly what to expect, your experience may not have spatial coordinates but, as Mach says, it certainly has temporal coordinates i.e., your experience cannot be wholly separated from its temporal representation: *how long* you have been expecting something.

But if this is so, given that space and time coordinates are the most primitive representations used by the sensory-motor system to refer and attribute features of the environment to objects, and given that time representation is even more fundamental than space representation, then it seems one must conclude that time representation is *the most primitive* of all the representations used by the sensory-motor system to interpret information.

Obviously, spatiotemporal representation is crucial to give the sensory-motor system more fine-grained discrimination powers and temporal coordination alone would be insufficient for an animal to be a successful interpreter of environmental information. As Clark says, in a ‘No-Space’ world, different instances of the same quality would only differ temporally and demonstratives would only be used to identify different moments in time. More specifically, information concerning the simultaneous instantiation of qualities at different regions would not be registered, e.g., two identical patches of red would not be distinguished as *two* or in the case of two cats “One might count a *series* of cat cries, but not simultaneously sensible cats” (Clark, 2000, 161).

However, temporal coordination alone seems to be (in some cases) enough for successful discrimination (as in the case of only *one* feature that is changing over time). And in many cases, one can think of sensorial and non-sensorial experiences that lack spatial information. Actually, one does not have to think of contrived cases in order to come up with a clear example of pure temporal coordination (a case of sensory-motor representation that lacks any spatial character). With respect to human olfaction, Clark writes,

> Two simultaneous presentations of an acrid odour fuse to one; and one cannot discriminate the presentation of something that is both acrid and musky from the simultaneous presentations of something acrid and something else that is musky. Of course one can still use one’s nose to distinguish an acrid thing and a musky thing from an acrid musky thing, but it requires successive sniffs and a generalization over times. (Clark, 2000, 160)

In No-Space olfaction, the sequence of sniffs does not produce a map of locations with sources of odors. It simply produces a series of experiences that have a temporal coordinate, which would allow a creature with the capacity for memorizing sequential sniffs to distinguish and catalogue different odors even in the absence of any spatial information.[5] Thus, time representation is more fundamental than space representation in the sense that there seems to be no possible sensorial experience without a temporal character, but there are sensorial experiences without a spatial character (or at least cases in which it is unclear whether or not spatial representation is involved).[6]

But I do not mean to suggest that space representation is somehow dispensable in solving the problem of individuating the contents of perception. The notion of a *place-time* is truly fundamental to solve this problem. Place-times provide an ordering of experiences that is unlike any other ordering that would be based on different qualities of sensorial experiences.

For instance, many qualities of sensorial experiences can occur at a single place-time simultaneously, but many place-times cannot occur in a single sensorial experience simultaneously.[7] This is why Clark says that sensory-motor place-times are the most primitive form in which the cognitive system represents *referents* and distinguishes between sensorial subjects and their predicates.

There are studies of spatial primitive representations in the philosophical literature that adequately address the scientific evidence (Clark's work is an example of such studies). But a philosophical study of temporal primitive representations based on the

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[5] A further assumption for this example to work might be that the creature should never move because in that case olfaction would have a spatial character. But it is not too hard to imagine such a case.

[6] Certainly, one can *imagine* No-Time worlds. The issue here is whether such worlds are psychologically possible. Another way of putting this is that a No-Time world is metaphysically and logically possible, but it is psychologically *impossible*, whereas a No-Space world is psychologically *possible*, as Clark's example of the olfaction system illustrates.

[7] Rudolf Carnap highlights this important difference in (1967, 145-146).

scientific evidence has yet to be done. My dissertation aims at filling this gap. In the next section, I outline its original contributions.

1.3. Outline of proposals

Spatial primitive representations can be understood in terms of cognitive maps, but how should temporal primitive representations be construed? In the next two chapters, I explain how there are two clocks (the circadian clock and the stopwatch) that produce representations with metric structure. The sensory-motor system uses these representations to produce spaces of possibilities for action. An innovative aspect of my account of the clocks is that it provides a general theoretical framework to classify interval and periodic clocks, which I then apply to the circadian clock and the stopwatch (chapter 2 is devoted to this issue).

In chapter 3, I explain why the representational outputs of the clocks have metric structure and propose that these representations are best characterized as analog representations. I postulate five criteria for analog representation and show that the outputs of the clocks satisfy these criteria, relying on experimental evidence to support my arguments. An important contribution of this chapter is that I define the representations of the clocks in terms of their isomorphic mapping to periods and intervals.

The explanation of how the two clocks work (provided in chapter 2) is essential to understand how their outputs map onto features of periods and intervals. The periodic cycles of the circadian clock allow the sensory-motor system to interpret its outputs in terms of phases of the period of 24 hours and use this information to predict periodic events and navigate. The elapsed intervals emulated by the stopwatch allow the sensory-motor system to interpret moments of an interval in an aperiodic way, thus producing representations of time in a non-periodic fashion.

But how are these representations *anchored* to the present moment? I answer this question in chapter 5, where I offer a novel two-phase model of the present. There have been a lot of proposals about how the experienced present is specious (not durationless and with earlier and later parts), but few have tackled the issue of the specious present in relation to spatiotemporal coordination and *none* have explained how the sensory-motor system relates clock representations to the present.

I solve these problems by proposing two phases of the present. One, which I call the *sensorial specious present* (SSP), is the relevant anchor for spatiotemporal coordination and the representation of simultaneity. And the other, which I call the *phenomenal specious present* (PSP), is the one that frames experiences and binds them together. The larger duration of the phenomenal specious present explains why it does not involve the representation of simultaneity. An important aspect of my proposal is that I rely on experimental evidence to justify the two-phase model of the present.

The model of the present that I offer reveals that the notion of being immediately acquainted with the present is ambiguous because it could be referring to the SSP or the PSP. This ambiguity has implications for debates in the metaphysics of time that appeal to our immediate acquaintance with the present, which I explain in chapter 5. I also discuss other possible implications of my proposals for the metaphysics of time, including my theses on the outputs of the clocks, in chapter 5, particularly section 5.4.

Chapter 2

Periodic and Interval Clocks: The Cases of the Circadian Clock and the Stopwatch

2.1. Introduction

The distinction between periodic and interval timing is one of the most powerful theoretical tools to approach the issue of temporal representation. It provides a fundamental categorization of representations of time based on the mechanisms that keep track of time in terms of periods and intervals. A careful assessment of the differences between periodic and interval timing brings to light aspects of timekeeping that are otherwise confused or blurred, and it should precede any analysis of temporal representation.

Although this distinction is relatively well known in the psychological literature, it has not been properly introduced in the philosophical literature. And even in the psychological literature, there is no thorough theoretical treatment of the main properties of periodic and interval timing. In this chapter, I intend to address these problems by providing a theoretical framework to classify periodic and interval timing based on the essential characteristic of periodic and interval clocks.

The framework I offer in this chapter is of interest to philosophers, psychologists and cognitive scientists in general, for the following reasons. First, it is difficult to have a meaningful discussion on time representation without understanding how timing mechanisms work. Getting familiarized with the specific challenges that measuring time poses is crucial to argue sensibly about temporal representation. The best way to appreciate these challenges is by distinguishing clearly between periodic and interval timing, which requires an understanding of the mechanisms underlying periodic and interval timing, i.e., periodic and interval clocks.

Second, I will demonstrate the usefulness of the framework I am offering in this chapter by applying it: I use it to distinguish the main characteristics of the circadian clock and the stopwatch. Although these biological clocks have been differentiated through careful experimentation and analysis, there is no theoretical treatment of the distinction between these clocks, as periodic or interval clocks, that I know of. However, many of the ideas I employ in developing this theoretical framework, and a significant portion of the evidence I rely upon, come from C. R. Gallistel's work, particularly Gallistel (1990).

Third, there are original contributions of my analysis of periodic and interval clocks, such as how they relate to each other and what principles govern their interaction. And fourth, with respect to methodology, I follow as closely as possible the scientific evidence. When I describe the most general features of periodic and interval clocks, I avoid speculating about unrealistic cases by exemplifying these features through real clocks that were designed throughout human history.

One of my goals is to demonstrate the existence of two types of sensory-motor representations of time in animals and humans, based on the framework I offer to distinguish between periodic and interval timing. I address the topic of sensory-motor representations of time in the next two chapters. In this chapter, I present the theoretical framework for distinguishing periodic and interval timing, which is an indispensable prerequisite to develop an account of sensory-motor temporal representation. It is important to mention that I do not make any preliminary unwarranted assumptions about representations of time in this chapter, and ground all my analysis on the characteristics of periodic and interval clocks.

The structure of this chapter is as follows. Section 2.2 provides a general description of different techniques for measuring and calculating time, which motivates the distinction between periodic and interval clocks. Section 2.3 provides a theoretical account of the main characteristics of periodic clocks and section 2.4 offers a theoretical account of the characteristics of interval clocks. In section 2.5, I compare periodic and interval clocks, emphasizing their advantages and disadvantages. In section 2.6, I apply my characterization of periodic clocks to describe the circadian clock and section 2.7 is a description of the stopwatch, based on my characterization of interval clocks.

2.2. Records of time

A sundial projects a shadow onto a disc or some type of base. This shadow keeps track of the trajectory of the sun from sunrise to sunset. The object that casts the shadow, also known as *Gnomon*, needs to be tall enough to cast a shadow that reaches the end of the circumference of the disc (or the relevant portion of the base) and it has to be at a particular angle (which is the latitude of the location in vertical sun dials) with respect to the disc or the base in order to cast a shadow continuously. The *Gnomon* also has to be thin enough to cast a narrow shadow that can be projected along the hour lines, which are numbered lines drawn on the disc or base.

Sundials are very interesting pieces of technology. They reveal mankind's need to control and understand time, as well as the enormous influence that representations of time have on our daily activities. It was because of the development of ever more precise sundials that we divided the day into hours. The period of 24 hours is a natural cycle—it marks the period of one complete rotation of the earth on its own axis, or more colloquially, the period that elapses from dawn to dawn. From a completely geocentric (and erroneous) perspective, 24 hours is the duration of the cycle in which the sun "travels" or makes its way through the sky to start a new cycle of daylight.

The period of 24 hours is one of the most important temporal cycles for many creatures living in our planet. In section 2.6 of this chapter, I describe the circadian clock, a biological mechanism that keeps track of time periodically, in cycles that approximate 24 hours. The period of one day is so crucial in our lives that we divide it carefully into hours, minutes and seconds. However, there are other important temporal cycles that are registered in many ways, each of them as fascinating and revealing as the way in which a sundial records time by projecting a shadow that *emulates* the trajectory of the sun across the sky, or the way in which the circadian clock *mimics* the period of one day by means of cyclical biological processes.

Tree rings record the passage of time periodically, in cycles of about one year. These rings can be seen in any tree if one cuts across its trunk horizontally. They form because of periodic changes that depend on the seasons, which have an impact on the growth of the tree, e.g., temperature and rain. As the tree grows and creates new wood, the periodic changes of the seasons are recorded in each of its rings and, thus, each ring demarcates a period of one year.[8] A very similar process occurs in ice, where seasonal changes in temperature and sun irradiance are registered in the layers of ice cores, as ice accumulates. These layers, like the rings of a tree, correspond to a period of one year.

[8] The technique for dating based on the study of tree rings is called *dendrochronology*. Dating based on tree rings has been a powerful tool in determining the atmospheric conditions of ancient environments.

Some registers of time cover much wider temporal ranges. Carbon-14 decays into Nitrogen-14 very slowly, within a scale of thousands of years. The rate of decay is quite reliable (Carbon-14 has a half-life of 5730 years) and it allows scientists to calculate the time at which a now fossilized creature was a living and thriving organism. But light (radiation in general) is the most amazing record of time with respect to temporal range. The speed of light is constant and if one calculates the distance that light has traveled from its source one can calculate the time it has traveled, because speed is distance divided by time. Cosmologists can calculate the distance that light has traveled because of the redshift of light (a shift in the wavelengths of light from higher to lower energy) produced by the accelerated expansion of the universe.[9] Using the redshift of the spectrum of light, scientists can estimate the time that light has traveled from extremely distant sources, making possible calculations of time in the range of millions and billions of years.[10]

These dramatically different scales of time (i.e., days, years, thousands of years, millions of years) are a source of wonder. But equally astonishing is the fact that time is recorded in nature in so many different and reliable ways. One can think of all these natural processes—the cycle of day and night, the seasons of a year recorded in tree rings

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[9] There are three kinds of redshift: Doppler, gravitational and cosmological. All are relevant for calculating time, but the most relevant for the present purposes is the cosmological redshift, which is caused by the expansion of the universe. There is an opposite process to redshift, which is particularly important to the Doppler effect. If the wavelengths are shortened, from lower to higher energy (which means the distance between source and observer is decreasing instead of increasing) the shift is called blueshift.

[10] The last calculation of the age of our universe indicates that it is approximately 13.73 billion years old. This estimate is based on the WMAP (Wilkinson Microwave Anisotropy Probe), and it is considered the most precise measurement of the age of the

and ice cores and the processes that lead to carbon dating and the redshift of light—as *natural clocks*. But there is a noticeable difference between the *cycles* of one day and one year, registered by the circadian clock of living organisms and by tree rings and ice cores respectively, and the long *intervals* of time registered by Carbon-14 and light.

Clearly, one could add the number of tree rings of a specific tree and calculate an interval of time in terms of years. But the process on which the registration of time depends upon is cyclical—it repeats itself over and over. This is manifestly not the case with Carbon-14 and light. There is no cycle on which the decay of Carbon-14 or the redshift of light depend upon. These different forms of timekeeping are very important to understand two fundamental ways in which animals and humans represent time. The remainder of this chapter is devoted to clarify the distinction between periodic and interval clocks and to expand on the characteristics of periodic and interval timing.

2.3. Periodic clocks

In this section, I focus on periodic clocks. I explain their most important characteristics and some of the advantages they have as registers of time. In section 2.4, I describe the characteristics and advantages of interval clocks and in section 2.5, I offer a comparison between periodic and interval clocks. This provides an important theoretical background that is necessary to understand how the circadian clock and the stopwatch work.

Periodic and interval clocks perform the same function—they register time. But they perform this function in very different ways, which have important implications for the topic of time representation. In order to appreciate the importance of the distinction

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universe to this day. Cosmologists use the redshift technique to map the universe, identify between periodic and interval timing, one must first understand the nature of the mechanisms that underlie these forms of timekeeping. As C. R. Gallistel says,

> Mechanisms or processes that make possible the recording of moments in time and the determination of temporal intervals come in two basic forms: oscillatory processes and nonoscillatory decay or accumulation processes. (Gallistel, 1990, 231)

Oscillatory processes and the mechanisms that produce them underlie periodic timing. In this section, I focus exclusively on oscillatory processes for periodic timing and their properties. In the next section, I discuss decay and accumulation processes for interval timing. Oscillatory processes are those that repeat in a regular fashion. Each repetition of a cycle occurs in accordance with a constant period of time that delineates the beginning and the end of the cycle: the end of one cycle marks the beginning of a new cycle. According to this definition, the rotation of the earth on its own axis, the rotation of the moon around the earth and the rotation of the earth around the sun are oscillatory processes. These processes repeat with a regular period and the end of one cycle marks the beginning of a new one.

These periods (a day, a lunar month and a year) are quite familiar to us.[11] However, other oscillatory processes have much shorter or longer periodic cycles. Examples of these cycles are the oscillations of a cesium atom (the mechanism underlying atomic clocks) and the rotation of the sun around the galaxy, or cosmic year. The cesium atom produces around 9 billion oscillations per second and the sun makes one rotation around the galaxy about every 200 million years. In spite of the significant differences in scale

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some of the most ancient cosmic events and the most distant galaxies.

[11] The period of the lunar month varies depending on how it is measured. Roughly it is between 27 and 29 days.

and physical instantiation, all these oscillatory processes share the following characteristics:

a) There is a constant period of time that delineates each cycle of the oscillatory process. This period is the time it takes for the oscillatory mechanism to complete one cycle.

b) The cycles repeat themselves one after the other in accordance to a constant period of time.[12]

c) There is no restriction concerning the physical medium that instantiates an oscillatory process. What characterizes an oscillatory process are properties a) and b).

Properties a) and b) are the foundation for the most important characteristic of periodic timing mechanisms: that the oscillatory mechanism is always at a particular *phase*. The phase of an oscillatory process is the stage of completion of one cycle. To determine the phase of an oscillatory process is equivalent to establish how much of the cycle has been completed. If one characterized a cycle as a circle, then the end of the cycle would correlate with 360 degrees (which is also the beginning, or 0 degrees), and the intermediate phases of the cycle could be characterized by the intermediate degrees that range from 1 to 359.

The fact that oscillatory processes and mechanisms are always at a particular phase is crucial to understand why such processes and mechanisms register time in a reliable

[12] Notice that the period of a cycle is very different from the frequency of an oscillatory mechanism. The frequency of an oscillatory system is a measurement of the number of cycles per unit of time. This unit of time is arbitrarily selected (it could be one second or one year) and it can differ substantially from the period of time in which the oscillatory mechanism completes one cycle.

way.[13] For instance, if two or more oscillatory mechanisms with the same periodic cycle are *phase-locked* (which means that these mechanisms share the same phase) then the phase of one such mechanism reveals the state of the whole system of phase-locked oscillatory mechanisms.[14] Moreover, oscillatory mechanisms can have different periodic cycles and yet maintain a fixed relationship. Gallistel explains why the hands of a clock are a good example of a fixed phase-relationship among cycles. He writes,

> On a clock, the period of the second hand is 1 minute, the period of the minute hand 1 hour, and the period of the hour hand 12 hours, but the phase relationship among these cycles is fixed. The second hand completes its circle just as the minute hand indicates the minute, and the minute hand completes its circle just as the hour hand indicates the hour. (Gallistel, 1990, 229)

Thus, the phase of an oscillatory mechanism is important to determine synchrony among oscillators with equal periods and also to fix relationships among oscillatory mechanisms with different periods, which is illustrated by the way in which the cycles of the hands of an analog clock are related. The phase of an oscillatory process makes possible the precise coordination of its cycle with the cycles of other oscillatory processes. This is why it is the most important characteristic of oscillatory processes with respect to registering time. By phase-locking their cycles and fixing phase-relationships,

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[13] In what follows, I will be mostly concerned with discussing oscillatory *mechanisms* because of their relevance for understanding the circadian clock. Processes are more pertinent to the discussion of interval clocks. I do not mean to draw a sharp distinction between processes and the mechanisms that underlie them. I am distinguishing one from the other based on the intuitive notion that mechanisms always produce the same result (just like oscillators always produce the same cycle). 'Process' is a more general category, not inherently related to reproducibility, which I think suits better what I have to say about interval clocks. In any case, nothing that I have to say hangs on this distinction.

[14] If two oscillatory mechanisms are *coupled* (which means that the phase of one mechanism changes the phase of the other, and their phase is different) then what determines their phase will be the dynamics between these mechanisms. This means that the relationship between their phases is not fixed and it changes with time.

oscillatory processes can reliably register time in many scales and in many different ways. And by reproducing a cycle with a constant period, oscillatory processes are clocks that keep track of time periodically. To conclude and reiterate, the most important properties of periodic clocks (which are the defining properties of oscillatory processes), are:

a) There is a constant period of time that delineates each cycle of the periodic clock. This period is the time it takes the clock to complete one cycle.
b) The cycles of the clock repeat themselves one after the other in accordance to a constant period of time.
c) There is no restriction concerning the physical medium that instantiates a periodic clock.
d) The clock is always at a particular phase.

These properties, all of which must be satisfied by a mechanism or process in order to qualify as a periodic clock, differ significantly from the properties that characterize interval clocks. The importance of the distinction between periodic and interval clocks will be evident in the discussion of the psychological data regarding timing mechanisms in animals and humans. However, before assessing the psychological evidence, it is important to distinguish periodic and interval clocks from a purely theoretical perspective. Having at hand the characteristics of periodic clocks makes much easier the task of defining interval clocks, which is the main goal of the next section.

2.4. Interval clocks

Unlike periodic clocks, interval clocks are best described as "one time" processes: there are no repetitions of cycles or representations of phases. This crude characterization can be made much more precise by comparing the main characteristics of interval clocks with the properties of periodic clocks. But first, before listing the characteristics of interval clocks, a couple of illustrations of the type of process that instantiates them would be useful. I will focus on two classic examples of interval clocks: the sand clock (or hourglass) and carbon dating.

The process by means of which a sand clock, also known as hourglass, registers time is, using Gallistel's terminology, a non-oscillatory *accumulation* process. It is non-oscillatory because it does not depend on the periodic repetition of cycles in order to register time. The stages of time-registration of a sand clock are not *phases* of a cycle, but rather *partitions* of amounts of sand that accumulate in the lower part of the sand clock.[15] The interval of time registered by the sand clock depends fundamentally on its spatial capacity, i.e., it depends on how much sand it contains, or how big it is.

Sand clocks depend on an accumulation process because the amount of time registered is correlated with the amount of sand that builds up at the bottom of the clock. Sand clocks need to be "started" by turning them around. The sand starts falling through the narrow tube of the clock and accumulates in its lower part, indicating how much time has elapsed. Generally, sand clocks have no partitions or lines that could indicate increasing intervals of time, although it is in principle easy to construct such a sand clock.

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[15] I have in mind the typical sand clock with a symmetrical shape, in which sand falls from the top part of the clock to the lower part through a narrow tube.

However, most sand clocks can only register whatever time interval can be correlated with the total amount of sand that the clock contains.

There are important physical constraints that sand clocks must satisfy in order to be reliable. For instance, the sand must flow continuously. This means that it must be thin (in proportion to the size of the clock), in order not to obstruct the tube, which would slow down the flow of sand, altering the measurement of the interval of time. Other physical aspects that change the constant flow of sand are the angle of the glass bulbs or containers, the width of the tube (it must be uniform), the size of the sand particles, and the position of the clock (it must be on a flat surface, otherwise it slows down).[16]

What makes a sand clock reliable is its constant rate of sand-flow. If this rate of flow fluctuates or changes, for instance because one of the previously mentioned requirements was not satisfied, then the clock is unreliable: it will speed up and slow down randomly and measure different intervals each time it speeds up or slows down. Once one considers all these physical constraints on the design of a sand clock and, most importantly, how easy it is for a sand clock to speed up or slow down, it is not a surprise that we only use them today to boil eggs or play desk games. But this does not mean that all interval clocks share these reliability problems.

Other accumulation processes, like the formation of layers of rock that serve as the basis for calculating the age of the earth, have a relatively steady rate of sedimentation.

[16] I am leaving out other equally important, but less obvious factors that affect the accuracy of sand clocks by altering their constant flow of sand. These factors are temperature, moisture, the density and weight of the sand particles and the smoothness of the surface of the glass.

There are, of course, climatic factors that change this rate.[17] But, in general, the rate is much less dependent on specific constraints, like those that determine the flow of sand in a sand clock. Another sedimentation process with an even more reliable-constant rate is the Erythrocyte Sedimentation Rate (ESR). It determines the rate at which red blood cells (those that carry oxygen) accumulate at the bottom of a test tube containing blood. The reliable rate at which red blood cells fall down to the bottom of the test tube allows doctors to diagnose blood related conditions, particularly inflammation. The diagnosis is based on whether or not the rate is the standard one.

Interval clocks can also be instantiated by decay processes. As mentioned, Carbon 14 is a very reliable interval clock because its rate of decay, though extremely slow, is quite consistent. The non-oscillatory *decay* process that serves as the basis for carbon dating does not have many of the problems that jeopardize the accuracy of sand clocks. First, there are no constraints with respect to position and other environmental situations that severely affect the rate of flow in the sand clock. If "left alone" Carbon 14 naturally decays into Nitrogen 14, and it is incredible how precise its rate of decay is—very few environmental conditions affect its rate of decay.

Decay processes are as diverse as accumulation processes. There is radioactive decay in many particles, besides Carbon 14, and many fermentation processes occur at a specific rate. A metaphorical, though not very precise, way of describing the difference between accumulation and decay processes is as follows. Accumulation processes are evidence that time always goes forward, making the past inexorably bigger and bigger.

[17] I clarify, in section 2.5.3 of this chapter, why tree rings and ice cores are related to periodic clocks and why the relatively constant rate of accumulation of layers of rock makes rock formations interval clocks.

Decay processes are evidence of the inexorable passage of time too, but they show how time destroys everything it touches, making everything that is actual no longer the case.[18] They are two faces of the same coin, but one emphasizes how the past grows and the other emphasizes how the present is ephemeral.

Accumulation and decay processes are the basis of interval timing. I have mentioned some of the characteristics of interval timing. I shall now make explicit these characteristics and contrast them with the properties of periodic clocks. The main characteristics of interval clocks are:

a) Interval clocks have a constant rate of accumulation or decay.
b) There is an activation event that starts the clock (an event that starts an accumulation or decay process). An interval is measured either by stopping the clock or by using its rate to deduce an interval. Interval clocks are started and stopped only once.
c) There are restrictions on the physical medium that instantiates an interval clock. The most important one is that its scale or size is inversely correlated with its resolution.
d) Interval clocks only register or represent *segments* of an interval, not *phases* of a cycle.

I proceed to explain these properties, all of which must be satisfied by a physical medium for it to qualify as an interval clock. Property a), the constant rate of interval clocks, is what makes them reliable timekeepers. I will illustrate this point with a

[18] Candle clocks, which measure intervals of time in terms of the rate at which a candle burns away, are a very good illustration of a decay process in which time "destroys" the medium used to measure it, i.e., the candle.

hypothetical sand clock. Suppose that you live in ancient Rome—where sand clocks were apparently used to time speeches—and you are commissioned to design a very precise sand clock, so that all the very important Roman politicians get exactly the same amount of time to give their speeches. You know a lot about sand clocks, and you proceed to get the best materials—the right kind of sand, glass, wood for the bases, etc. Once you are done, how do you test if the clock is reliable?

You could start using the clock to time many things, like concerts, theater presentations, and so on. You could also compare it to other very reliable clocks for measuring the same interval and see if they match by finishing at the same time. But this will not suffice to guarantee that the clock is always measuring the exact same interval. For it is possible that the concerts and theater presentations have quite different durations, just like other sand clocks might be measuring quite different intervals. Your clock might be matching these different durations and intervals because its rate of sand-flow is fluctuating. So, the problem is how to control for fluctuations in the rate at which the sand flows?

The only solution is to tackle the problem directly—the clock has to be stopped at different moments and the amounts of sand that are falling at different moments need to be measured. Before sealing the clock by attaching the bases to the glass structure, you need to determine how much sand is flowing, say at three different moments: when the clock is full, half full and almost empty.

You go ahead and in very brief amounts of time marked by a drumbeat played by a musician (for the sake of simplicity, assume that these brief intervals are one second long) you collect the amount of sand that fell from the top of the clock. You verify, to your satisfaction, that at each moment, marked by the drumbeat, you collect 50 particles of sand. This means that the rate of sand-flow is constant, i.e., 50 particles per second.[19] Now you know that no politician is going to worry because the clock is flowing faster when it is full or is changing rhythm randomly. This example illustrates that an interval clock's accuracy depends entirely on its constant rate of accumulation or decay.

Property b) can be explained in more simple terms. With respect to information, all interval clocks give the same kind of output: they calculate an interval from a starting time *t1* to another time *t2*. These moments in time coincide with the activation and deactivation of the interval clock. In the case of a sand clock, *t1* would be the moment in which the clock is turned around, so that sand can start falling, and *t2* would be the moment in which there is no more sand at the top of the clock. Regardless of how long or short the interval is, all interval clocks are activated and deactivated, and these events coincide with the beginning and the end of the interval measured by the clock.

The property that makes a manifest physical difference between periodic and interval clocks is property c). There are two aspects about property c), which I will label C1 and C2—and both of them are very relevant to the physical instantiation of interval clocks. C1 concerns a general constraint on the *resolution* of interval clocks and it can be stated as follows: there is an inverse correlation between the scale of the durations that an interval clock can measure and its resolution. In other words, the larger the scale of the intervals, the poorer the resolution of the clock, and vice versa.

[19] Small deviations from this rate, such as 53 particles per second, will not affect significantly the accuracy of the clock. But how much deviation is allowed depends on how accurate one wants the clock to be.

Think again about the hypothetical sand clock. You have an extremely accurate sand clock that has a very reliable constant rate. But now you want to determine how long are people clapping to one of the speeches. You could use the speech-clock and stop it when people stop clapping. Then you can estimate what is the proportion between the interval that corresponds to the amount of sand collected at the bottom and the interval that the clock calculates. You can actually count the sand particles in order to be more precise—you know that the rate is constant, 50 particles per second. Counting the particles would give you a very good approximation to the exact duration of the interval that elapsed.

But clearly, this is very messy. Counting the particles means that you have to disassemble the clock every time you want to measure a smaller interval. Stopping the clock takes some time, which will be unfortunately added to the interval that you are trying to measure. You may try to compensate this by anticipating the end of the clapping, but any anticipation will subtract time from the interval being measured. Moreover, the clock has to be tilted every time you stop it, which means that the flow of sand slows down and its rate changes. Thus, your approximation will never be as good as the precise measurement of the interval that the clock was designed to calculate.

Things get much worse if the intervals to be measured are very small. The smaller they get, the worse your approximations will be. Actually, if you wanted to be ambitious and calculate intervals of 10 milliseconds, you would find out that sand particles are too coarse to calculate such intervals. So, in spite of its accuracy, the sand clock for speeches is useless to calculate very short intervals. Now suppose that you build a "dust" clock for very short intervals. Its resolution is great: the particles are extremely small, which allows you to measure ever-smaller intervals of time. But now how do you go about measuring the duration of speeches, or banquets with the short-scale clock? The scale/resolution tradeoff is an insurmountable problem. Property C1, which characterizes all interval clocks, is also instantiated in decay processes. As Gallistel says: “Carbon 14 dating is useful for specifying the century in which a camp fire was built but not which year” (1990, 237).

C2 is deeply related to C1. Actually, C1 is a consequence of C2, which is a constraint on the type of process that underlies interval clocks. Accumulation and decay processes are ubiquitous in nature. Those that count as interval clocks must comply with property a), i.e., they must accumulate or decay at a constant rate. This rate depends on increases or transformations of a *medium*, which could be any physical substance or material. In the case of accumulation processes, there is an increase in the amount of a particular substance or material. And in the case of decay processes, there is a transformation of a substance or material into something else.

C2 imposes a very significant constraint on interval clocks: the medium that instantiates the clock must be such that it either accumulates or decays at a constant rate. This substantially reduces the set of possible materials that could serve as interval clocks, which is confirmed by the fact that periodic clocks are more abundant in nature, as well as less prone to fluctuations in their accuracy caused by changes in the media that instantiate them.

Take, for instance, the period of one day caused by the rotation of the earth on its own axis. There might be many transformations in the atmosphere and material constitution of the earth, but the period of its rotation will not fluctuate because of these changes. And the medium of a pendulum, which experiences *no accumulation or decay processes*, is a paradigmatic example of a periodic clock. Thus, there is no restriction concerning the physical medium that instantiates a periodic clock, which is property c) of periodic clocks. But, as I have explained, there is a significant constraint on the instantiation of interval clocks, i.e., that the *media* that instantiate them must accumulate or decay at a constant rate.

Finally, I will briefly explain property d), which is a consequence of property b). The activation process that marks the first moment of the interval being measured, or *t1*, is also the beginning of a *measurement* that will conclude at some point in the future. The two extreme moments of this measurement, *t1* and *t2*, delineate the moments of activation and deactivation of the clock. There is no *periodicity* or repetition of any kind involved in this measurement. It is simply an expanse of time that is best described as a *line*, rather than a *circle*. Since no cycle is involved, partitions of this measurement are simply segmentations of an expanse of time, not phases of a cycle. This is going to be very relevant for issues concerning the representation of time based on periodic and interval clocks, which I address in the next chapter.

It should be clear at this point that periodic and interval clocks operate in very different ways. Humans have used both of them to represent time. Sections 2.6 and 2.7 of this chapter are devoted to the fascinating psychological evidence that has identified two clocks that animals and humans routinely use to measure and represent time, which can be categorized as periodic and interval clocks respectively. There are many interesting topics related to the design and history of periodic and interval clocks that I will not address here. However, I will mention some of them very briefly before concluding this section.

Periodic and interval clocks are registers of time. But if one focuses on the type of representations they generate, they correlate with the cyclical and linear conceptions of time, which have generated so much debate in historical, sociological and anthropological studies. The distinction between cyclical and linear conceptions of time is also of interest to scientists, because the asymmetry of time that generates a direction (or arrow of time) from the past towards the future only makes sense in linear time. If time loops back in a cycle and time travel is possible, then no distinction between past and future is tenable. But these are specific ways of thinking about time, not ways of registering it.

There is also a very interesting historical dimension to the development of timekeepers and their role in the organization of human societies, from ancient to modern times. There are sociological, political and religious aspects of our obsession with measuring and representing time. Conceptions of time, both cyclical and linear, have profound repercussions on how we conceive of ourselves. Myths of creation, annihilation, death and resurrection rely heavily on these conceptions. These are fascinating issues, but they must be addressed independently of the topic of how periodic and interval clocks work and what is their relevance for psychological findings, which is the topic that concerns me in this chapter. I shall now proceed to compare periodic and interval clocks and then examine the psychological data on the circadian clock and the stopwatch in the light of the distinction between periodic and interval clocks.

2.5. A comparison between periodic and interval clocks

In this section, I discuss some of the advantages and disadvantages of periodic and interval clocks. For the sake of simplicity in presentation, I will focus on the disadvantages, stressing how the other type of clock fares better in overcoming a particular problem. It is important to compare periodic and interval clocks for two reasons. The first is that it clarifies some of the fundamental differences between periodic and interval clocks. And the second is that comparing these types of clocks is extremely useful to understand the representational properties of the circadian clock and the stopwatch, which I examine in more detail in the next chapter.

I first describe, in subsections 2.5.1 and 2.5.2 the disadvantages of periodic clocks and interval clocks respectively. In subsection 2.5.3, I address the issue of interfacing periodic and interval clocks. I introduce two principles governing the interaction between periodic and interval clocks that will be very important for sections 2.6 and 2.7, where I discuss the characteristics of the circadian clock and the stopwatch.

2.5.1. Disadvantages of periodic clocks

There are three disadvantages of periodic clocks, which concern mainly property c) of periodic clocks (unrestricted constraints on media), but relate to all other properties. The first disadvantage I discuss is that periodic clocks do not capture, as well as interval clocks, our intuitive notion of time. This is a disadvantage because the visualization of certain properties of time that philosophers and scientists find intuitive and extremely relevant, like the passage of time, is not facilitated by cycles and their representations. Second, periodic clocks do not convey information about the magnitude of durations explicitly. And third, these clocks confound different moments in time. I proceed to explain these disadvantages of periodic clocks.

Interval clocks are analogues of their intervals.[20] By this I mean that, as the interval gets larger, so does the medium that instantiates an accumulation-interval clock. And in the case of decay-interval clocks, as the interval gets larger, the closer one gets to the transformation of the medium into something else. An example of this analogue-way of registering time in the case of an accumulation clock is the sand clock, whose properties I have discussed in some detail. The main point is that the analogues of durations are amounts of sand: larger durations correspond to larger amounts of sand.

A decay clock that illustrates nicely this type of analogue interval registering is the candle clock. Instead of increasing proportionally to an interval, its medium (wax) decreases proportionally. By melting away and transforming its shape, the thin candle that instantiates the clock exemplifies quite literally how time passes, and moves forward relentlessly. Numbered marks on the candle delineate discrete intervals of time. As the candle melts away, these marked portions of the candle progressively disappear, which allows one to stop candle clocks at a certain interval.

Periodic clocks are also analogues of the cycles that they emulate. But periodic clocks are always repeating the same phases within a cycle. The media of periodic clocks do not get bigger as durations elapse, or decay accordingly. This aspect of interval clocks, i.e., that their media grow or decay proportionally to an interval, facilitates visualization, and it appeals to our intuitive understanding of time. For instance, it illustrates the intuitive

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[20] I am using the term 'analogue' in a non-technical way. By it, I only mean that there is an analogy between intervals and media, which consists in *increasing proportionally in*

ideas that time *flows at a particular rate*, *that it advances towards the future, that the past gets constantly bigger and that the present moment is ephemeral*. Periodic clocks have the disadvantage that they do not capture as well as interval clocks our intuitive notion of time because they do not facilitate the *visualization* of these intuitive ideas by not analogizing media with intervals in terms of their magnitude.

The second disadvantage of periodic clocks, which is very related to the one I just mentioned, is that the visualization of intuitive properties that we attribute to time, that interval clocks make possible, includes the visualization of the magnitude of intervals. This disadvantage can be stated in terms of information as follows: periodic clocks are not adequate to convey information about magnitude *explicitly*. This is a significant problem because information about magnitude is fundamental to define metric properties of time. For instance, it is common to define time as being one-dimensional and compare its structure with the metric structure of a line that can be segmented into ever-smaller portions, just like an interval of time can be segmented into ever-smaller intervals.

The analogy between the structures of a line and an interval is manifest, or *explicitly encoded* in the media of interval clocks because a line can be considered as an idealization or geometric representation of the physical process of accumulation or decay of an interval clock. The distance that exists between different moments of an interval is explicitly encoded in the *medium* that instantiates the clock, as is illustrated by candle clocks. This *explicitness* of the encoding of information about the magnitude of an interval, which periodic clocks lack, is important because interval clocks convey magnitude information directly, by increasing their size or decaying at a particular rate.

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magnitude. In the next chapter, I will define *analog* representations, and I will use the

Another way of saying this is as follows: knowing how much time has elapsed requires information about when one should start measuring an interval (or when did an interval start). This information is explicitly encoded in interval clocks because the first moment of the interval being measured corresponds to the moment of activation of the clock, or *t1*. As I explained in the previous section, the activation of the clock marks the beginning of an accumulation or decay process that characterizes all interval clocks: it is property b) of interval clocks. Information about the beginning of an interval is *not* encoded in periodic clocks. Knowing that a periodic clock is at a particular *phase* tells you nothing about the beginning or end of an interval.

However, I say that interval clocks encode magnitude information explicitly and directly because there is an indirect way in which periodic clocks can be *used* to calculate intervals. A phase of a periodic clock *per se* gives no information about when an interval started, but if one obtains this information through other means and knows how it relates to the cycles of a periodic clock, then it is possible to calculate intervals. But it is a real disadvantage of periodic clocks that information about *when* an interval started is simply absent in any of the phases of its cycle.

Finally, periodic clocks are not adequate to individuate specific moments of time by distinguishing them from other moments. As Gallistel says: "Unlike methods based on recording the states of oscillatory processes, this method [interval timing] has the advantage that it does not confound different moments in time—moments that correspond to recurring phases of a cyclical process." (1990, 237) This is basically the same disadvantage as the previous one, except that the limitation consists not in the lack

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term 'analog' in a technical way.

of information about the *magnitude of an interval*, but in the lack of information about *individual moments* in time.

A phase of a periodic clock *per se* gives no information about individual moments. This is because a particular phase of the cycle of a periodic clock corresponds to an unknown and, in principle, infinite number of individual moments. If one selects a phase of a particular cycle one can effectively convey information about a moment in time, but one cannot individuate such moment. The problem is that the *same phase* picks out many other moments that correspond to other cycles of the periodic clock. So, knowing that the cycle is at a particular phase gives no information about any *specific* moment, as the following example shows.

You can use the phase ‘sunrise’ (a phase of the periodic clock instantiated by the rotation of the earth on its own axis) to convey information about a moment in time, say the moment you were born. Knowing that it was sunrise when you were born does not tell you anything about *how long ago* you were born or *when* is your birthday. Actually, knowing that it was sunrise when you were born gives you as much information about the moment of your birth as knowing that it was sunrise when a Neanderthal woke up informs you about the time in which Neanderthals were alive.

Phases do not give information about specific moments in time and, for all you know, these two events (your birth and the Neanderthal’s awakening) might have happened at the same time and, thus, be the *same moment* characterized by the phase ‘sunrise’. However, if one has access to information about specific moments through other means—i.e., by using a memory register, or a calendar—then one can *use* a periodic clock to identify individual moments in time.

In contrast to the lack of information about specific moments that limits the informative power of periodic clocks, interval clocks distinguish moments explicitly by accumulating or decaying at a specific rate. Going back to the previous example, if one had an interval clock of a large enough scale, like Carbon 14, one could differentiate the time in which Neanderthals were still alive and our times. It would then be easy to differentiate sunrise1, when the Neanderthal woke up, and sunrise2, the moment of your birth, as two distinct moments in time. To summarize, periodic clocks have three important disadvantages as time registers:

1. They do not capture our intuitive understanding of time.
2. They do not convey information about the magnitude of durations explicitly.
3. They confound different moments in time.

2.5.2. Disadvantages of interval clocks

I will explain four limitations of interval clocks. The first is that there is always a scale/resolution trade-off in interval clocks. The second is that they cannot be related to one another in a reliable mechanical way. This imposes significant limitations on the possible ways in which a set of interval clocks can be manipulated, which I describe in some detail. Third, interval clocks lack sensitivity to periodicity. And fourth, they lack automatic, self-generated processes that could mechanize behavior, which makes them *user dependent* timekeepers. I proceed to explain these disadvantages.

As mentioned, a very significant disadvantage of interval clocks is that there is always a scale/resolution trade-off: property c). I described in section 2.3, using the example of two sand clocks with different scales (one for debates and the other for very brief intervals), how this problem affects all interval clocks. Periodic clocks do not have this problem. As long as their period remains constant, they are incredibly reliable and, since they repeat their cycle regularly, it is possible for them to cover very large, as well as extremely small, scales. Since their media do not have to emulate an interval, scale is not a limitation for periodic clocks. Periodic clocks with very short periods can cover vast amounts of time because their cycles repeat for vast amounts of time.

Another crucial disadvantage of interval clocks is that they cannot be related to one another in a reliable mechanical way. As I discussed in section 2.2, there are at least two fundamental ways in which different periodic clocks can be related. The first is by being *phase-locked*: if a set of clocks are in the same phase and their cycle has the same duration, then the state of the phase of one clock reveals the state of the whole system of phase-locked clocks. Discovering that a set of clocks are not phase-locked may also be important and informative, because then one can determine the lack of synchrony within a system, which may reveal interesting dynamics between the oscillatory mechanisms of the periodic clocks.

The second way in which different periodic clocks can relate to each other, even if they have different periodic cycles, is by maintaining a fixed relation, which I also described in section 2.2. In the case of interval clocks, there is no genuine relationship that could resemble or be compared to the relations between the phases and cycles of periodic clocks. Even if one tried to build a contrived multiple-layered system of interval clocks, the end result would be a contrived *interval clock* that complies with all the characteristics of interval clocks I mentioned in section 2.3. This is in sharp contrast with periodic clocks. Being phase-locked or having a fixed phase relation to other clocks is a genuinely advantageous way in which a periodic clock can relate to other periodic clocks.

One does not end up with a contrived periodic clock when one has a system of phased-locked clocks or a set of clocks with a fixed relationship: each clock keeps its own cycle and the relations among them are genuine ones. I proceed to explain these claims.

For the sake of thoroughness, I will give two illustrations of contrived relations among interval clocks and show how these relations are not genuine, reliable or mechanically reproducible. Imagine that you want to build a system of synchronous interval clocks, the equivalent of the phase-locked set of periodic clocks. All the interval clocks are reliable and flow at a constant rate. Their media could include sand, wax and water.[21] But, in order to simplify things, suppose that they are all sand clocks made with the same materials. How are you going to achieve synchrony among these clocks?

Because of property b) of interval clocks, they have to be *activated* at the same time. But then the synchrony is not achieved by the clocks, but rather by *your activating them* at the same time. What if you want to keep in synchrony 1000 interval clocks? That would be a nightmare. In contrast, two, or a hundred or a million periodic clocks might just *happen* to be phase-locked, something that is actually quite common in nature, and their synchrony will be maintained by their periodic cycle *automatically*.[22]

Even if you have to phase-lock the clocks, their synchrony is guaranteed by their constant period and you do not have to phase-lock all of them at the same time, which

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[21] Water clocks are as old as sundials, probably one of the first ways in which humans kept track of time.

[22] For those who are curious about how ubiquitous these synchronous phase-locked oscillatory processes are, see Strogatz, S. (2003) *Sync: The Emerging Science of Spontaneous Order* and references therein. The author, a mathematician, claims that synchrony between oscillators is inevitable, based on the mathematics of coupled oscillators. Just to give a sense of the variety and scope of oscillatory processes that phase-lock, here are some of the cases of synchrony that Strogatz analyzes: synchronal

allows you to avoid the multiple-activation problem. The phase-lock relation among these clocks is genuine because it fully depends on their phase and period. However, the synchrony imposed on interval clocks is fully dependent upon when they are activated by a user and their synchrony is, therefore, not a genuine relation among them. Granted, synchrony is still a relation that holds among them, but one that has been artificially achieved by external manipulation, rather than by the internal characteristics of interval clocks, as the multiple-activation problem reveals.

What about trying to build a set of interval clocks with a fixed relationship? This is the case in which different interval clocks turn into one contrived interval clock. Suppose you have a source of water that flows to a channel at a constant rate. Once this channel is full, say after a minute, it empties its content into a container that fills up every hour. The channel keeps filling up and emptying out its content. How, one might ask, is this different from the fixed relationship of the minute hand and the hour hand of an analog periodic clock? The difference is a fundamental one: this water clock is a contrived interval clock that, unlike an analog periodic clock, offers no advantages as a timekeeper because of the following reasons.

First, once the hour container is full, it spills. So this is really a *one-hour* interval clock. Suppose that there are other containers that accurately measure two, three, four hours and so on. There is a limit as to how many hours these clocks will measure. Moreover, because of property c) of interval clocks, once we get to the biggest container, say a gigantic pool of water, we will not be able to distinguish one hour from two or more hours. The easiest way to deal with this problem is to *empty* the container of the hour

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flashing of fireflies, satellite orbits, the chirping of crickets, the menstruation of women clock every hour (every time it fills up) and then keep track of the hours by counting them. But then, it is the *user* of the clock who is keeping track of the hours. There is no fixed relationship between the hour container (the hour clock) and larger-scaled ones, like the big pool of water. Their relationship depends on how *the user keeps track of these containers*. Unlike a set of periodic clocks, which keep their phase relationship fixed in a *mechanical* fashion, a set of interval clocks require constant *monitoring by their user*.

What about the relation between the hour container and the minute one (the channel)? Again, there is no fixed relationship between these containers: their relation depends on how the user keeps track of their contents. It is true that if the minute interval clock accelerates its rate, then the hour interval clock's rate will accelerate accordingly. But what we have in this case is a *single bad hour clock* that accumulates water at a fluctuating rate. The amounts of water that the minute clock pours are only smaller intervals of this bad hour clock. If we think of the minute interval clock as an independent clock, then monitoring will be required in order to keep track of every time it empties its content. But then it will be the user of this contrived hour clock who keeps track of the minute clock. Thus, there is not a single genuine relationship among interval clocks and all their possible relations depend on their user. This is why relations among interval clocks are contrived, not reliable and not mechanically reproducible.

The third disadvantage of interval clocks is their lack of sensitivity to periodicity. This is an important shortcoming when the environment has a vast number of periodic events happening regularly, as is the case on earth. If at sunset there is apple pie for free at the coffee shop, knowing when to run to the coffee shop is quite easy if one has a

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living close by, insect outbreaks, human sleep and superconductors.

periodic clock of 24 hours that could be used as an alarm clock: one only needs to phase-lock the clock to 'sunset' and then, mechanically and automatically, one will always get on time for free apple pie.[23] But if one has an interval clock of 24 hours, then one needs to activate this clock after each apple pie meal, and worry if one activated it on time for the next day. The clock by itself would go ahead and end its interval. If the user is not careful, and activates the clock 2 hours after having apple pie, then she will be two hours late for apple pie tomorrow and reduce her chances of eating. This is very bad if your entire diet consists of apple pie.

Finally, a disadvantage that is implicit in what I have just said, particularly concerning the second and third disadvantage, is that interval clocks are much more user dependent than periodic clocks. The automatic processes of periodic clocks (e.g., recurrent cycles, fixed phase relationships and phase-locking) are an incredibly important basis for *automatic behavior*, sensitive to periodicity and temporal information. Interval clocks literally run out of whatever media instantiates them and stop, but periodic clocks are, as it were, *always running*. This is a crucial advantage of periodic clocks that creatures endowed with a circadian clock, which are basically all creatures on earth, exploit constantly, as I will explain in the next section.

To conclude, I will summarize the four disadvantages of interval clocks I have discussed and then proceed, in the next subsection, to describe how periodic clocks can be interfaced with interval clocks, thus allowing for a hybrid or mixed timekeeper. Some important disadvantages of interval clocks are:

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[23] This is assuming that 'sunset' always happens at the same time, which is not the case in many latitudes on earth. But for the sake of the example this assumption is not

1. That there is always a scale/resolution trade-off.
2. That they cannot be related to one another in a reliable mechanical way.
3. Their lack of sensitivity to periodicity.
4. Their lack of automatic, self generated processes that could mechanize behavior and the corresponding user dependence.

2.5.3. Hybrid and semi-hybrid clocks

A way to overcome the inconveniences of periodic and interval clocks is by designing a hybrid or semi-hybrid clock. There is an important distinction that needs to be highlighted between a hybrid clock and the *use* or *interpretation* of a periodic or interval clock according to information external to, or not encoded by, the clock. For instance, dating based on tree rings and ice core layers is in a sense a hybrid technique for timekeeping because scientists have to *interpret* the accumulation of the layers produced by these *periodic* clocks as constituents of an *interval* clock. But scientists have other information, such as calendars, to compare tree rings and ice cores in order to determine intervals of time in terms of years. And the dating of events depends not only on calendars, but also on other technical calculations, such as those based on Carbon 14. If a scientist were given a tree trunk or an ice core sample and nothing else, dating the rings or layers of ice would be close to impossible.

However, because they are *registering* year intervals, trees and ice cores are *semi-hybrid* clocks. The mechanism that produces the annual cycle encoded by trees and ice cores is the rotation of the earth around the sun, which is a periodic clock. But the fact that trees and ice cores register this period of time by *growing* makes them semi-hybrid

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problematic. However, as I will explain, periodic clocks can be re-phased so that they are clocks in the following sense: it is not by *accumulating at a constant rate* that makes these clocks accurate, because trees and ice cores need not have a constant growth or accumulation rate in order to accurately encode periods of one year. They only need to grow, and it does not matter if their growth rate fluctuates. So, they are semi-hybrid clocks because they have a register for periods of one year, instantiated as wood and ice, and a *reliable periodic clock* that marks these periods (i.e., the rotation of the earth around the sun).

Notice that the name semi-hybrid is adequate because it would be a mistake to attribute any of the properties of interval clocks to tree rings and ice cores ('semi-hybrid' means that the mechanism is a combination of a clock and a register, rather than a combination of *two clocks*). I already explained why tree rings and ice cores do not comply with property a) of interval clocks (their constant rate), which entails that they cannot be characterized as interval clocks. But they do not comply with other properties too, such as c), because tree rings and ice core layers need not emulate an interval: having a register, they can cover very large as well as very small scales and still have excellent resolution for periods of about one year. In contrast, sand clocks, and interval clocks in general, emulate intervals of a specific scale and share the scale/resolution problem. Thus, tree rings and ice cores are semi-hybrid clocks because they are used as *registers* of a periodic clock: they are not the combination of an interval and a periodic clock.

A truly hybrid clock combines a periodic clock with an interval clock, each of them satisfying their respective properties. The ideal combination is a periodic clock that determines the rate at which an interval clock accumulates. If one represents equal

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always phase-locked to an event, even if the event recurs at different times.

accumulation segments in terms of numbers, then one would obtain a hybrid clock with an oscillatory mechanism that feeds information to a counter. (Notice that numerals, which make the accumulation process a *counter*, are representations imposed on the accumulation process, and they are not necessary constituent parts of the clock.) This is the most accurate way we have come up with to measure time.[24]

Examples of hybrid clocks are the atomic clock and the stopwatch, which I describe in section 2.7. It is important to distinguish carefully between the *register, or memory for events*, such as a counter or a calendar, and the *clocks*, which are exclusively devoted to timekeeping. With respect to the principles governing the combination of clocks, there are 4 possible ways in which clocks can interface:

1. The combination of two or more periodic clocks with the same or different periods.
2. The combination of two or more interval clocks.
3. The combination of an interval clock with a periodic clock, where the periodic clock determines the interval clock's constant rate.
4. The combination of a periodic clock with an interval clock, where the interval clock measures the durations between phases of the periodic clock.

I argued that (1) is a significant advantage of periodic clocks and against (2), I argued that there are no genuine relations among interval clocks. (3) and (4) are interesting cases of clock-combination, and they are governed by the following principles:

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[24] The atomic clock simply counts the transitions of a cesium atom. The optical clock is based on the same principle and it is even more accurate than the atomic clock. Our use of numerals allows us to simply count oscillations, but if we lacked numerals, an interval clock that grew at a constant rate marked by these oscillations would do a similar job.

Truly Hybrid (TH): In the case of the combination of an interval clock with a periodic clock, where the periodic clock determines the interval clock's constant rate, the resulting hybrid clock will be an *interval clock*, which means that it will comply with the characteristics of interval clocks and the periodic clock will only be relevant to keep its rate constant.

Periodic Segmentation (PS): In the case of the combination of a periodic clock with an interval clock, where the interval clock measures the durations between phases of the periodic clock, there is no *genuine combination of clocks*. The periodic clock's phases are not *determined* by intervals. Rather, the interval clocks are *used to measure* the duration of segments of the periodic clock's cycle.

As mentioned, the atomic clock and the stopwatch are cases of hybrid clocks that comply with (TH), as my discussion on the stopwatch in section 2.7 of this chapter illustrates. Computations on periodic clocks, performed for the purpose of calculating *intervals*, comply with (PS). Having addressed these important issues, I shall now proceed to explain the circadian clock and its relevance for the representation of time in living organisms.

2.6. The circadian clock

In this section, I describe the circadian clock and analyze its most important features. I first provide a brief introduction to the findings on biological rhythms, including *ultradian* and *infradian* biological cycles. In subsection 2.6.1, I discuss entrainment, in the context of experimental evidence concerning the circadian clock. Finally, subsection 2.6.2 is an assessment of two types of representations based on the circadian clock: sun-compass navigation and memory for time of occurrence.

The circadian clock is a *periodic clock* with a cycle of about 24 hours, which emulates the rotation of the earth on its own axis. Although there are other oscillatory processes that could be considered as biological clocks, such as those involved in lunar, seasonal and annual rhythms, the circadian clock (and its corresponding daily rhythm) is by far the most important, and most studied, biological clock. Scientists have found that plants, fungi, bacteria and animals have circadian clocks, which regulate a vast variety of rhythmic behaviors.

The fact that circadian clocks have been scientifically identified in organisms as different as bacteria and plants is astonishing. There are fascinating aspects of circadian rhythms. Perhaps the most mind-boggling one is that the circadian clock regulates very important biorhythms, from the genetic to the organism levels. This explains why the circadian clock is often referred to as the 'master clock'. For instance, the circadian clocks of different animals influence niche formation and biodiversity in ecosystems by partitioning animals into diurnal and nocturnal. From gene transcription to sleep cycles, the circadian clock's impact on an organism and its environment is truly incredible. As Panda and Hogenesch (1998) explain:

> Circadian modulation of gene transcription translates into rhythmic activity of their protein products, which in turn generates rhythmic metabolic flux in different tissues and rhythmic behavior and physiology at the organism level, thereby enabling the animal to adapt to diurnal changes in its environment. (Panda and Hogenesch, 1998, 375)

There are many other interesting issues about the circadian clock that have been discussed in the vast literature that its multi-disciplinary study has generated. However, I shall focus only on the most general aspects of the circadian clock that make it an accurate periodic clock, and on its relevance for the representation of time in organisms.

But, before addressing the characteristics of the circadian clock, I will first introduce some technical terminology concerning the distinction between the circadian clock and other biological oscillatory mechanisms and their corresponding biorhythms.

The period of the cycle of the circadian clock is so important that other biorhythms are defined in terms of the circadian rhythm ('circadian' literally means *about one day*: 24 hours). *Ultradian* are those rhythms and oscillatory processes that occur more frequently than every 24 hours. These ultradian rhythms may determine a biological cycle within one of the rhythmic functions regulated by the circadian clock, such as sleep. For example, Daniel F. Kripke (1973) has identified a 90-120 minutes ultradian rhythm that regulates the alternation between rapid and non-rapid eye movement sleep. This ultradian oscillatory process has also been related to waking gastric activity and brain functions during wakefulness related to fluctuations in attention (Kripke, D. F., 1972; Hiatt, J. F. and Kripke, D. F., 1975).

Biological rhythms that occur less frequently than every 24 hours are called *infradian*. Some examples of infradian cycles are the menstrual, lunar and circannual cycles ('circannual' means *about one year*). Circannual cycles have been identified in hibernating mammals, such as ground squirrels (Michener. G. R., 1979) and woodchucks or groundhogs (Concannon, P. W. et al, 1992). Lunar cycles have been identified in sea creatures, which have lunar clocks that allow them to synchronize their biological rhythms with tidal changes. A fascinating example of an animal with a lunar clock is *Clunio marinus*, a type of fly.

The larvae of *Clunio marinus* are extremely sensitive to moonlight. Fleissner, G. et al (2008) found that the *ocelli* (photoreceptor organs that could be considered as primitive eyes) of the *Clunio marinus* larvae change their shielding pigment transparency according to a lunar-rhythmic cycle. This allows the larvae to adjust to changes in light intensity, which depend on various factors including tidal changes. The fact that the shielding pigment transparency of the larval ocelli changes according to a lunar cycle strongly suggests that *Clunio marinus* has a lunar clock that regulates these changes.

The list of ultradian and infradian rhythms (and the ultradian and infradian clocks that produce them) keeps increasing. Animals are finely tuned to periodic changes in their environment and have developed clocks to track important periodic events. Chronobiology will certainly produce more exciting and unexpected results concerning ultradian and infradian rhythms. However, the circadian clock is the most important biological clock because of two reasons.

First, its biological basis and functions have been identified in animals and plants, and studies reveal that the circadian clock regulates a vast percentage of rhythmic behavior. And second, which is the most relevant issue for the topic of time representation, the circadian clock of animals with nervous systems plays an important role in producing representations of the environment concerning navigation and time of occurrence. I proceed to explain the main characteristics of the circadian clock—relating them to the general characteristics of periodic clocks—and to justify these claims.

2.6.1. Entrainment

Entrainment occurs to all biological clocks that produce biorhythms, or which are *periodic bio-clocks*, and it correlates with the capacity of periodic clocks to have fixed phase relationships, including synchrony. When there is a fixed relationship between an *environmental* periodic clock and a periodic *bio-clock with the same period*, their cycles are phase-locked, like in the case of the circadian clock, whose cycle is phase-locked with the cycle of the rotation of the earth on its own axis. The circadian clock (or any other periodic bio-clock) is *entrained* by maintaining a fixed phase relationship to an environmental cycle, in the case of the circadian clock, the cycle of day and night. If a bio-clock is entrained, then there is another periodic event to which the bio-clock is phase-related. As Gallistel explains,

> The process by which the influence of one oscillation on another holds that other oscillation in a fixed or preferred phase relationship is called entrainment. Endogenous self-sustaining oscillations enable animals to synchronize their activity with cycles in the environment (and with their conspecifics) because these oscillations are entrained by timing signals from extrinsic oscillations or from other oscillators within the same organism. (Gallistel, 1990, 223)

An oscillator that influences another oscillator is called the *master oscillator* and the one that changes as a result of the influence of the master oscillator is called a *slave oscillator*. In the case of the circadian clock, the master oscillator is the period of 24 hours in which the earth rotates on its own axis. This periodic clock determines the cycle and phases of the circadian clock, which is in this case, a slave oscillator.

However, within a particular organism, the circadian clock determines the cycles and phases of many other oscillators and this is why the circadian clock is also known as the master clock, because in these cases it is the master oscillator. Entrainment is the relationship that holds between a master and a slave oscillator: the slave oscillator is entrained by certain *cues* from the master oscillator, just like the circadian clock is entrained by certain cues from the environment, usually light.

But what exactly is the influence that the master oscillator has on the slave oscillator? By maintaining a fixed phase relationship, changes in the master oscillator's cycle re-set the phases of the slave oscillator. These changes are cues that trigger a shift in the phases of the entrained periodic clock. Suppose that you isolate an entrained periodic clock from the cues of the master oscillator that are relevant for re-setting its phases and cycle. Then the entrained periodic clock is said to be "free running" and although it can still reproduce its cycle accurately (in the case of the circadian clock, every 24 hours) its phase relationship with the master oscillator has been severed.

The circadian clock of plants illustrates this point. Since plants depend mostly on sunlight for their survival, it is no surprise that their circadian clock can be *re-set* by manipulating light cues. However, they reproduce their circadian rhythm even in the absence of light. Andrew J. Millar (2003) explains that:

> Circadian rhythms in plants are relatively robust, as they are maintained both in constant light of high fluence rates and in darkness. Plant circadian clocks exhibit the expected modes of photoentrainment, including period modulation by ambient light and phase resetting by brief light pulses. (Millar, 2003, 217)

The plant's circadian clock is accurate even in the absence of light, when it is *free running*. But its period can be modulated by light intensity and its phases are re-set by light cues. When the circadian clock is free running there is a *phase-drift* that indicates how significant is the mismatch between the circadian clock's cycle and the external cycle that entrains it. If the phase-drift is very significant, then the circadian clock will have to transiently accelerate or slow down its pace until it can re-establish the phase relationship with the external cycle again. This holds for all circadian clocks, as is illustrated by the circadian clocks of cockroaches and hamsters (See Gallistel, 1990, 229-231)

Entrainment has an enormous significance for the survival of living organisms that have bio-clocks. All the advantages of periodic clocks are manifest in entrainment (i.e., mechanically reproducible relationships to other periodic clocks, sensitivity to periodicity and automatic behavior). Entrainment is responsible for keeping living organisms in tune with their environment, including other animals and conspecifics. For example, certain phases of the clock could be phase-related to the periodic presence of prey, which is an identical situation to the one I described in section 2.5.2, where I offered the apple pie example. But the most dramatic example of a set of synchronized phase-locked bio-clocks in nature is the existence of swarms of insects or birds that reproduce or feed at the same time.

The automatic and reliable mechanisms that underlie entrainment are present in all living organisms. Circadian rhythms are equally present throughout nature. I mentioned plants and animals, but I could have talked instead of bacteria and fungi.[25] However, nervous systems and brains provide the possibility of using circadian clocks to register information about the environment, and thereby constitute a *semi-hybrid clock*, composed of a periodic clock and a memory-register.[26]

Plants have photoreceptors and a complex biochemistry that underlies their circadian clock. But plants do not seem to have a semi-hybrid clock that they could use. They are best characterized as having a *natural periodic clock*. As we go up the scale of neural complexity, organisms with nervous systems are able to encode information in memory. In the case of vertebrate animals, who possess the most complex nervous system (composed of a central and a peripheral nervous system) the registration of information in the brain creates a very sophisticated *semi-hybrid natural clock,* constituted by the circadian clock and the brain's memory-register.

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[25] See Golden, S. S., and Canales, S. R. (2003) for circadian rhythms in cyanobacteria and Dunlap, J. C. and Loros, J. J. (2006) for circadian rhythms in fungi.

However, even the small network and set of ganglia that constitute an insect's nervous system is powerful enough to produce an amazing semi-hybrid clock, with enormous repercussions for the animal's behavior. I proceed to describe the representations encoded by animals with semi-hybrid clocks.[27]

2.6.2. Circadian clock representations

A great achievement of modern biology was to identify the suprachiasmatic nucleus (SCN) as the locus of the master circadian clock in mammals. This periodic clock, like in the case of many other living organisms, synchronizes central and peripheral oscillations. The SCN is located in the hypothalamus, above the brain stem. The neurons of the hypothalamus and the brain stem regulate neurological functions necessary for survival, and the biochemical reactions that underlie these vital functions are kept in synchrony by the SCN. The circadian clock of other creatures is, like the SCN, also responsible for regulating vital functions.

Other neural networks of the brain can utilize the information contained in the neurons of the SCN. In the case of creatures that are not mammals, their ganglia or brains can utilize information from their circadian clock, whichever way it is instantiated. This generates a neural semi-hybrid clock as follows: the SCN instantiates the periodic circadian clock, and other regions of the brain instantiate a register for information concerning the SCN (and similarly with other neural systems).

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[26] For a brief characterization and discussion of semi-hybrid clocks see section 2.5.3 of this chapter.

[27] What about trees? I said that they are semi-hybrid clocks, but this is because *we use them* as semi-hybrid clocks. Clearly trees and ice-cores cannot *use* the information contained in their registers for annual cycles. The difference is that animals with nervous systems can use the information stored in their brains.

Other specialized areas of the brain may utilize information from the circadian clock to compute duration, rather than periodicity, but the circadian clock will remain a periodic clock. This is related to what I said about semi-hybrid clocks and principle (PS) concerning the use of interval clocks to measure phases of a periodic clock. The difference is that in this case there is no interval clock measuring phases, but rather computations on information stored from the circadian clock determine the length of intervals. (PS) still holds because these computations of duration do not transform the circadian clock into an interval clock. I will present two cases, tested experimentally, of how information obtained from the circadian clock can be utilized by other specialized areas of the brain for representational purposes. One of them concerns navigation and the other the registration of time of occurrence.

2.6.2.1. Navigation and the solar ephemeris function

It seems counterintuitive that a self-sustaining and automatic mechanism like the circadian clock could be used in sun-compass navigation, which depends entirely on environmental information. However, when other specialized areas of the brain properly interpret information obtained from the clock, the circadian clock can become a powerful component of a navigation system. It would be inaccurate to say that the circadian clock is used *as a clock* in sun-compass navigation. What is being used is information concerning certain phases of the clock that get interpreted as *spatial* information concerning the angle and position of the sun. Insects and birds can perform such navigational computations. The experimental challenge is to confirm that they are indeed using information from the circadian clock.

The idea is that sun-compass navigation in animals might exploit phase information from their circadian clock to compute the position and angle of the sun in order to determine orientation by fixing which direction is north. How to test this hypothesis experimentally? The easiest way is to design an experiment that tests whether changes in the phases of the clock correlate with predictable changes in orientation during navigation. As Gallistel says, a way to demonstrate the existence of an internal ephemeris function "that gives the sun's azimuthal position as a function of the time indicated by an animal's endogenous circadian clock is to put the endogenous clock out of phase with the local day-night cycle (so-called clock-shifting experiment)." (1990, 81)

Gallistel describes experiments that demonstrate that animals indeed use their circadian clock to compute the ephemeris function. M. Renner (1960) trained bees in Long Island to fly to a feeding station north of their hive at a compass bearing of 315 degrees. He then packed the bees at night and flew them to Davis, California. Gallistel explains:

> The time difference between Long Island and Davis is a little more than three hours, which means that the azimuthal angle of the sun at Davis is on average about 45° behind its azimuthal angle on Long Island. The bees from Long Island were jet lagged when their hive was opened at Davis; their endogenous clocks were roughly 3 hours ahead of the day-night cycle at Davis. When a bee whose internal clock is 3 hours ahead of local time tries to use the sun to set a northwesterly course, it will in fact set a westerly course; it will orient approximately to 315° - 45° = 270°. This is what the bees did at Davis, proving that their ability to steer by the sun depends on an endogenous ephemeris function linked to their endogenous circadian rhythm. (Gallistel, 1990, 81)

Similar results have been confirmed in experiments on ants (Wehner, R. and Müller, R., 1993) and homing pigeons (Emlen, S. T., 1975). It is remarkable how information from the neurons that instantiate the circadian clock is transformed by other regions of the brain into spatial information for navigation. This requires specific metric information that maps onto features of the environment. The brain uses circadian clock information to compute the ephemeris function, which is the result of a powerful combination of representations with *metric structure* (a topic that I will examine in the next chapter). But the following example of circadian clock representations is more pertinent to the topic of temporal representation because it is a case of what I described as a semi-hybrid clock, instead of a navigation system-component.

2.6.2.2. Time of occurrence

Experiments on the capacity of animals to register the time of occurrence of events were originally based on the observation that insects, birds and mammals *anticipate* the availability of food within a specific range: not too early because that would only be a waste of time, but not too close to the arrival of conspecifics and other competitors before food is available, because then anticipating the availability of food would not be advantageous. This kind of anticipatory behavior has been confirmed in bees, birds and rats.[28] The question is how are these animals anticipating events and registering their time of occurrence?

There are two possible explanations for anticipatory behavior, based on the characteristics of the circadian clock. The first is that a particular event is *associated* with a phase of the circadian clock. The memory for the time of occurrence would be phase-dependent (also known as state-dependent) because it would only be available to the animal when it is in that phase of the cycle. There is no *register* for times correlated with phases. Rather, there are only the phases of the circadian cycle identified with some kind of marker that indicates to the animal that food is about to arrive.

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[28] See Gallistel, C. R. (1990, 243-286) and references therein.

The animal learns how to anticipate events by associating these events with phases of the circadian cycle through repetition: the more frequent an event at a phase, the stronger the association. In order for the marker to activate and produce anticipatory behavior, the animal has to be at the phase of the circadian cycle that correlates with such marker. This is a model for time of occurrence that relies exclusively on the circadian clock and its capacity to *phase-relate* periodic events to its circadian cycle through entrainment.

To illustrate this point, visualize the circadian clock of the bee (or bird or rat) as a Ferris wheel with only one gondola. The animal is "sitting" in the gondola as the wheel spins. The wheel has a cycle of 24 hours and the gondola where the animal is sitting has a screen that tells the animal what to do. When there is an important event (like feeding) the screen displays the message 'food' and registers the event by marking the phase of the cycle at which the event happened. Every time the wheel is at this phase, it displays the message 'food', but the animal has no access to that information at any other time. Since the period of the cycle is 24 hours, the message produces behavior in the animal every 24 hours. Adjustments to changes in time are accommodated by entrainment. Anticipatory behavior can be explained by the capacity of the circadian clock of animals to adjust to phases that *optimize* feeding, regardless of whether these phases precede the availability of food. Call this model the *phase-based* model.

The alternative model is based on a semi-hybrid clock, constituted by a clock (the circadian clock) and a register or memory *for* times, rather than a phase-based memory. The main difference with the previous model is that times of occurrence are registered in memory, along with other information, and thus the animal has access to this information at any time (not only at the times that correlate with a phase). This does not mean that phase information is no longer relevant: mismatches between the phases of the clock and periodic environmental events, because of phase-shift, will disorient the animal, which will have to entrain the clock. However, the information concerning phases and events will be available to the animal at any time. Call this model the *memory for time* model.

The *phase-based* model is attractive because it is based on a simpler, more economic (in terms of brain power) and self-sustaining or automatic mechanism: the circadian clock. Researchers on biological rhythms tend to favor this model because of the overwhelming evidence in support of entrainment in circadian clocks, which explains how animals can learn to anticipate food availability. In principle, plants and rats might be using the same phase-based model. In the case of plants, phase-based information "tells" the plant how to balance water, when to change its position and orientation in order to absorb more light and how to optimize energy consumption within the 24 hours cycle of the circadian clock.

In the case of the rat things are more complicated, partly because the nervous system of the rat is much more powerful than the set of sensors of the plant, but the model might be the same. Phased-based information from the circadian clock might alert the rat about all sorts of things: when to get food, when to wake up, sleep, increase levels of activity, etc. Why should we introduce the assumption that memory and extra computations are needed to provide an accurate model of the anticipatory behavior of animals?

The main evidence in favor of the memory for time model comes from experiments on anticipatory feeding behavior in bees, which seriously undermine the phase-based model. A series of experiments conducted by R. Kolterman, in 1971, demonstrate that bees can distinguish 19 *different* times of the day, which were correlated with different odors. Crucially, they can learn information about times after only a single day's training.[29] According to Gallistel, the relevance of these experiments is:

> Kolterman's experiments clearly demonstrate that it is the time of day at which the training experience occurred rather than the periodicity of training experiences that is important. He trained his bees in a single day. In one of his experiments, the bees experienced geraniol on three successive visits over a 15-minute period beginning at 10:00 and then again for another three visits at 11:00. The only periodicity in this feeding schedule is the 1-hour periodicity. Since the training was done on a single day, there was no 24-hour period in the training schedule. (Gallistel, 1990, 253)

Before I explain why this is extremely strong evidence in favor of the memory for time model, I shall emphasize that phase information is crucial for this model: these representations stored in memory are *readings* of the circadian clock at a particular phase.[30] This is demonstrated by the fact that the bees' behavior in the next day correlated with the phases of the circadian cycle and not with the 1-hour period of the training schedule because their search behavior *did not repeat every hour*. Rather, the bees searched *only at the phase* of the cycle were they experienced the geraniol. However, the finding that bees learn how to time their search in *a single day* according to feeding time, rather than the periodicity of feeding recurrence (1 hour), plus the finding that they can distinguish 19 different times of the day, challenges the phase-based model on two fronts.

First, if animals are using their circadian clock to anticipate events, as many experiments suggest, then it is difficult to explain how they can learn information about times within a 24 hours period without using a register for time of occurrence. If periodicity and entrainment are the main mechanisms underlying anticipatory behavior, then the prediction of the phase-based model is that the circadian clock must go through

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[29] See Gallistel (1990) and references therein for details and further discussion on Kolterman's experiments.

at least one cycle of 24 hours in order to mark certain phases as behaviorally significant. But the bee data from the Kolterman experiments prove this prediction wrong. Bees could learn schedules of only 1-hour period and distinguish as many as 19 different times within only one cycle of the circadian clock.

Second, the finding that bees can associate odors with times shows that there is information stored in a register, suggesting the existence of a computational semi-hybrid system, rather than a single periodic clock. Thus, the memory for time model is the one that best accounts for the bee data. Similar findings, which give further support to this model, have been confirmed in the rat.[31] These findings suggest that the probability of other organisms with brains having such semi-hybrid clocks is high.

I discussed two types of circadian clock representations. But what kind of representations are these? How can they be characterized using current theories of mental content? The main purpose of the next chapter is to address these questions. I shall briefly mention that what distinguishes these representations is their *metric structure*. It seems that only animals with brains (and a complex nervous system that supports a semi-hybrid timekeeper) are capable of representing circadian information for sun-compass navigation and time of occurrence. The evidence favors the memory for time model, but there are two models that researchers discuss, one of which dispenses with the register and stresses the mechanical self-sufficiency of the clock. The situation is significantly different in the case of the stopwatch, because the two competing models are both

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[30] In the next chapter, I explain how these readings are computations on the outputs of the clock.

[31] For a detailed discussion on the evidence for the memory for time model in the rat see Gallistel, 1990, pp. 277-285.

dependent upon memory, registration and representation. I proceed to describe the characteristics of the stopwatch.

2.7. The stopwatch

The so-called 'stopwatch' is an *interval clock*. It is a biological interval clock, neurologically instantiated in the brain, with a short scale, ranging from seconds to minutes. Neuroscientists are investigating whether there might be different interval clocks that make possible the registration and production of sub and supra second intervals in different modalities (Meck, W. H. and Malapani, C., 2004). There is intense debate concerning the location of an interval timing mechanism for motor and non-motor activity, and the evidence favors the existence of a distributed network of neurons, rather than a single region of the brain (Bhattacharjee, Y., 2006).[32] This distinguishes the neural correlate of interval timing from the neural correlate of the periodic circadian clock, which is located in the hypothalamus, specifically in the SCN. For the sake of simplicity, I will focus on the characteristics of the stopwatch, assuming that it is a single mechanism, but if it turns out that there is more than one stopwatch, that would not challenge what I am about to say because, as I will explain, all these timekeepers would behave like interval clocks.

An interesting question is why would animals with circadian clocks, brains that allow the registration of information in memory and even other clocks for ultradian and infradian rhythms, evolve *another* clock for short intervals? This interval clock is not only very different from the periodic clocks just mentioned, but also seems to be

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[32] This evidence on the neural correlate of interval timing is based on experiments on humans. I will discuss evidence on neural mechanisms for interval timing in animals when I address the issue of the rate of the stopwatch.

distributed throughout the brain, rather than located at a specific region. The most plausible explanation, put forward by scientists, is that the stopwatch is deeply related to attention and sensorial information, and is used to make sense of temporal information coming from different sensorial sources.

The cross-modal nature of the information processed by the stopwatch fits well with its being distributed in a network of neurons that would be communicating with the specialized areas of the brain where the different modalities are instantiated. This means that the stopwatch is likely to have evolved later than any periodic clock, which also fits well with the fact that the circadian clock is ubiquitous throughout nature: it seems to be a very old part of the brain and of the mechanisms that sustain life in general. The thesis of the recent evolution of the stopwatch receives further support from the significant amount of brainpower it requires, because it seems to be responsible for estimating intervals concerning information coming from the senses.

The recent evolution of the stopwatch can also be argued for on the basis of the advantages that calculating intervals of seconds and minutes, *without representing periodicity*, offers to an animal.[33] Gill, F. B. (1988) has shown that the hermit hummingbird's ability to forage efficiently (and even mate, in the case of the male) depends on its ability to represent temporal intervals with great precision. In the case of the hummingbird, an interval clock is not only an advantage: it is actually *indispensable*. As Gallistel explains:

> The problem the bird confronts is inherently one of representing elapsed intervals rather than periods because the environmental variation to which it must adapt is aperiodic. Flowers do not fill and empty themselves cyclically. They fill themselves

[33] For evidence on the capacity of animals to represent elapsed intervals with fixed interval schedules see Gibbon, J. (1977) and Killeen, P. (1975).

> at a more or less steady rate […], and they are emptied by various foragers. (Gallistel, 1990, 289)

Thus, in a complex environment where events that are crucial for the survival of an animal occur aperiodically, having a stopwatch is a huge advantage. A lot of the processes that occur in nature are periodic, and this is the reason why periodic clocks are present in all living creatures. But in an environmental niche, where there is constant competition, aperiodic events become commonplace. However, besides its probable recent evolution, what are the properties of the stopwatch?

The stopwatch is a *hybrid clock* because it ultimately depends on the neural oscillations of the brain to keep its rate constant. But, for all intents and purposes, it is an interval clock because it complies with principle (TH), as I am about to demonstrate.[34] Moreover, all the models that psychologists have offered to develop a theory of how the stopwatch works describe it as an interval clock. If the stopwatch is indeed an interval clock, one should find all the characteristics of an interval clock in the stopwatch, just as one finds all the characteristics of a periodic clock in the circadian clock. Indeed, the stopwatch complies with all the characteristics of an interval clock. I proceed to justify this claim.

Property a) of interval clocks, their constant rate, has been identified in the stopwatch by manipulating the biochemistry of the brain. Experiments have shown that certain substances accelerate the stopwatch's rate, creating the impression of time "slowing down", or decelerate its rate, creating the opposite effect (Cheng, et al, 2006). Dopamine seems to be relevant to keeping the stopwatch's rate constant because it improves motor and non-motor interval timing and also because dopaminergic antagonists slow down the stopwatch's rate while dopamine agonists speed it up.[35] A neurobiological cocktail seems to maintain the stopwatch's rate constant and it is the neural equivalent of having a good sand clock by getting everything right (e.g., sand, glass materials, angle of precipitation, etc.)

Property b) of interval clocks corresponds to the activation and deactivation of the stopwatch. This process of activation and deactivation is correlated with attention, which means that the agent *activates* the clock by attending to a stimulus or set of stimuli and *deactivates* the clock by shifting attention or by decreasing the allocation of attention. In an experiment by Coull, J. T., et al. (2004), which tested non-motor interval timing, increases in attention in the timing task increased brain activity in specific areas of the brain. Meck and Malapani (2004) report the main results of this experiment as follows:

> The study made use of dynamically changing visual stimulus attributes (e.g., color and duration) that could be differentially attended to by the participants. Increasing attentional allocation to the temporal integration of stimulus duration selectively increased activity in a cortico-striatal network that included the pre-supplementary motor area, the right frontal operculum, and the right putamen. Conversely, increasing attention to the integration of the temporal variation in the color of the stimulus (rather than its duration) selectively increased activity in visual area V4. Thus, by parametrically increasing the attentional demands of the psychophysical task these researchers were able to identify the neural substrates of time and color perception. (Meck and Malapani, 2004, 133)

The relevance of this finding for the topic of the activation and deactivation of the stopwatch through attention is that the stopwatch, which integrates the duration of stimuli, works similarly to a sense organ. The allocation of attention to the duration of stimuli serves as the activation event that starts the stopwatch, and it stops when the allocation of attention drops. There is no periodicity involved in this mechanism and thus,

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[34] See section 2.5.3 for discussion on principle (TH).

[35] See Meck and Malapani (2004) and references therein.

no possible way of modeling it in terms of entrainment or phase relationships. The activation and deactivation events of the stopwatch correspond exactly to the general property of interval clocks that makes them dependent on a user that activates and deactivates the clock.

Property c) of interval clocks might be the main reason why psychologists needed to distinguish interval clocks from periodic clocks. The scalar property of interval timing that corresponds to property c) of interval clocks (experimentally demonstrated by Gibbon et al, 1984; Church et al, 1994; Malapani and Fairhurst, 2002) is briefly described by Meck and Malapani (2004) as:

> One of the major hallmarks of interval timing and reflects the observation that the variability associated with the precision of the "internal clock" grows in proportion to the length of the interval being timed. (Meck and Malapani, 2004, 135)

In other words, the degree of error in calculating intervals increases proportionally with the duration of the interval. The scale-resolution tradeoff is the foundation of the scalar timing theory, developed originally by John Gibbon.[36] As mentioned, this tradeoff is a consequence of the physical constraints on the medium that instantiates the clock, i.e., its constant rate and its capacity to emulate an interval. I will explain aspects of the scalar timing theory (particularly the importance of Weber's law) in the next chapter, where I examine sensory-motor representations of time with metric structure. But it is important to highlight that property c), which is fundamental to characterize interval

[36] There are alternatives to the scalar timing theory, but they all have to account for the scalar property that underlies Weber's law. The consensus is that there is no need to postulate several theories because the scalar timing theory is sufficient to explain the data on interval timing. For a detailed introduction to scalar timing theory see Meck, W. H. (2003).

clocks, is equally fundamental to characterize the stopwatch and its interval timing computations.

Finally, property d) of interval clocks is that they only register or represent *segments* of an interval, not *phases* of a cycle. This has two consequences for the components of the interval timing mechanism. Gibbon et al. (1984) describe different components for interval timing: clock, memory and decision components. Strictly speaking, the clock component is the one that corresponds to the stopwatch but since the characteristics that define interval clocks apply to interval timing in general, the three components can be considered as part of the stopwatch.

Property d) implies that the memories stored in the stopwatch are quite different from the memories that determine time of occurrence based on the circadian clock because there is no periodicity or phase information concerning durations. As mentioned, there are two models for circadian-clock based behavior: the phase-based model and the memory for time model. In the case of the stopwatch, the two competing models, which I am about to describe, require memory. I suggested that the memory for time model provides the best explanation of the data on time of occurrence in animals. If this is true, then humans and animals with brains complex enough to have different senses, have two ways of registering time:

1. A phase-dependent format for memorizing the outputs of the circadian clock that contains information concerning periods; and

2. A phase-independent format for memorizing the outputs of the stopwatch that contains information about durations independently of any cycle.[37]

The same holds for the representations of the clocks. Circadian clock representations are periodic, and stopwatch representations are not. The stopwatch represents an interval's duration without any information about *periodicity* or recurrence of events. But if there are at least two components of the stopwatch e.g., clock and memory, how exactly do they interact? Many neuroimaging studies have tried to dissect the contribution of these different components (See Meck and Malapani, 2004). The Coull, et al (2004) experiment is an example of such studies. But besides the effort to locate the neural correlates of the components of the stopwatch, researchers must also develop a model of how the stopwatch works in terms of the information it computes.

An interesting question that arises in the context of modeling the stopwatch is the following. Since the stopwatch is an interval clock, what kind of physical process is it relying upon: an accumulation or a decay process? There are two models of the stopwatch: the pacemaker or accumulator model, proposed originally by Gibbon in 1970; and Meck and Matell's striatal beat frequency (SBF) model. I proceed to describe these models.

The pacemaker or accumulator model, as its name indicates, characterizes the stopwatch as an interval clock instantiated by an accumulation process. This model theorizes that the activity of certain neurons generates pulses at a constant rate. Then these pulses are registered and accumulated by other neurons. As Bhattacharjee (2006)

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[37] See section 2.5.2.2 for discussion on the distinction between a phase-based model and a *phase-dependent memory for time model*.

says, this accumulation process happens "in the same way that a cup placed under a steadily dripping faucet accumulates drops of water" (597). Bhattacharjee continues:

> As the receiving neurons register more and more signals, the sense of time that has passed grows. Moreover, quantities of accumulated pulses corresponding to specific durations are recorded in long-term memory, allowing an individual to compare newly encountered time intervals to those previously experienced. (Bhattacharjee, 2006, 597)

The pacemaker or accumulator model has been the most influential model of interval timing to this day. It explains fundamental issues, such as the scalar property mentioned above, and it also provides a framework for explaining data on the stopwatch and for predicting behavior in experiments on interval timing. But Warren Meck (once a strong supporter of the accumulator model) and his collaborators have recently criticized this model. Meck's main criticism is that the accumulation process postulated by the pacemaker model is too simplistic and does not capture the complexity of neural activity, which does not accumulate linearly as the model assumes.

Meck and Matell (2004) provide the SBF model as an alternative, which they claim has the same predictive and explanatory power of the accumulator model without its problematic assumptions concerning neural activation. The basic idea behind the SBF model is that low frequency oscillations are used by striatal neurons to learn and recognize patterns of synchronous activity across different neural regions. These patterns are then correlated with *intervals* and the stopwatch can calculate intervals by selecting a particular pattern.[38]

It is unclear whether the process of selection of a pattern of activation by striatal neurons should be considered as a decay process. It is clear that SBF dispenses with the

[38] For details see Meck and Matell (2004) and references therein.

accumulator component of the stopwatch. If it is not an accumulation process, then the best way to describe it is as a probabilistic process in which a set of possible patterns of activation suddenly collapses into a single pattern. This process could be considered as a decay process because it depends on the physical transformation of a medium (neural oscillations) into something else (a definite pattern correlated with an interval.

But however it is conceptualized, it is important to mention that SBF has been strongly criticized by some neuroscientists, such as M. N. Shadlen, who has described the model as "pure fantasy", based on the ubiquitous nature of synchronous spikes in the cortex.[39] Neuroimaging and behavioral data will certainly generate more controversy. SBF is an innovative and plausible model that might eventually become the prevailing theoretical framework to explain how the stopwatch works. But, at the present moment, the only safe thing to say is that the stopwatch is an interval clock instantiated in the brain across different neural regions.[40]

To conclude, I have offered empirical evidence that demonstrates the existence of neurologically instantiated mechanisms that keep track of time. One of them, the circadian clock, computes periodic representations of time that are used for sun-compass navigation and for the registration in memory of the time of occurrence of periodic events. The other mechanism is the stopwatch, which computes representations of time in terms of duration, and not in terms of periodicity. These mechanisms and their representations need to be classified in a broader account of mental representation that

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[39] See Bhattacharjee (2006).

[40] Gallistel (1990) has also offered an alternative model for interval timing. Moreover, he has recently put forward a strong objection against both models of the stopwatch. I briefly comment on these issues in the next chapter (specifically page 101) because they concern computational and representational topics.

relies upon current views in the philosophy of mind and cognitive science. The main purpose of the next chapter is to provide a theoretical account of these temporal representations.

Chapter 3

Sensory-Motor Representations of Time: Outputs of the Clocks

3.1. Introduction

In the previous chapter, I categorized timing mechanisms into periodic and interval clocks. I explained why the circadian clock is a periodic clock and why the stopwatch is an interval clock. In this chapter, I address issues concerning the representational outputs of the clocks, e.g., what are the criteria they must satisfy to be considered representations, what kind of representations are they and what kind of information do they contain? I answer these questions by reviewing the philosophical literature and by selecting theses on mental representation that most aptly describe the outputs of the clocks, while paying close attention to the experimental evidence.

A very important property of the outputs of the clocks is that they are representations with *metric* structure. I define metric structure and explain how this structure allows for the cognitive integration of the outputs of the clocks with other metrically structured representations. Understanding how cognitive integration occurs is fundamental to appreciate the important role that the clocks play within the sensory-motor system. I show how the clocks are two independent systems for temporal representation whose outputs are crucial for motor coordination and action.

The structure of this chapter is as follows. Section 3.2 is an assessment of issues on representation and isomorphism. I explain why the temporal representations of the circadian clock and the stopwatch need to be understood in terms of isomorphism, and describe the different properties of the isomorphic representations of periods and intervals.

In section 3.3, I focus on considerations concerning the structure of these outputs and argue that the structure that frames these representations is metric, i.e., it preserves information about magnitude. I review the relevant experimental evidence on the metric structure of the outputs of the clocks and discuss it in two subsections, one of them devoted to the circadian clock and the other to the stopwatch. I then explain the importance of the metric features of these representations, such as their relation to Weber's law.

Finally, in section 3.4, I argue that the best way to account for the metric structure of the outputs of the clocks and their isomorphism with respect to periods and intervals is by characterizing these outputs as *analog* representations. I present five criteria for defining analog representation, and demonstrate that the outputs of the clocks satisfy all these criteria. Indeed, this section shows that the outputs of the clocks are *paradigmatic* cases of analog representation.

3.2. Representation and isomorphism

John Heil (2005) says that 'disposition' "is a term of art: you can define dispositions as you please."[41] I believe that the same is true about the term 'representation': you can define it as you please. However, as Heil also says, some ways of defining a term are more felicitous than others. Felicitousness depends ultimately on capturing the specifics of a particular case. Defining artistic or scientific representation poses specific challenges that are very different from the challenges one faces in defining mental representation. But even in the case of mental representation, there are different types of representations that generate their own definitional challenges.

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[41] Heil, J. (2005), p. 343.

With respect to the representations on which I focus in this chapter, i.e., the representations of time that correspond to the outputs of the clocks, the best way to capture their specific characteristics is by taking what J. L. Bermúdez (2003) calls a *minimalist approach* to nonlinguistic thought. Taking this approach is important because the sensory-motor representations of time produced by the circadian clock of animals and by the stopwatch are best described as measurements, or representations with metric structure. It would be inappropriate to characterize these representations in terms of language or particularly, propositional attitude psychology.[42]

The minimalist approach, as Bermúdez describes it, is "an alternative way of construing the project of explaining the behavior of nonlinguistic creatures in psychological terms" (2003, 62). Bermúdez continues:

> The minimalist proposal is to take the psychological states attributed in such explanations to be nonpropositional, analyzing them on the model of perceptual states rather than propositional attitude states. The thoughts attributed to nonlinguistic creatures on the minimalist approach are context-bound, essentially tied to the creature's capacities for action and reaction, perceptually vehicled, and lacking the constituent structure characteristic of propositional thought. (Bermúdez, 2003, 62)

The representational outputs of the clocks satisfy these properties. They are context-bound because they emulate environmentally relevant periods or intervals. They are essentially tied to the creature's capacity for action and reaction because they are a crucial part of the sensory-motor system. In the case of the circadian clock, its representations are used to calculate the time of occurrence of periodic events, which underlies anticipatory feeding behavior. Circadian clock representations are also used to compute calculations for sun-compass navigation that are critical for the animal's

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[42] Even in the case of propositional attitude attribution it is debatable that a linguistic-propositional model should be adopted instead of a more minimalist one. For a detailed

capacity to successfully interact with its environment and with other creatures. Similar considerations apply to the representations of the stopwatch, which as I mentioned in the previous chapter, are critical to make sense of cross-modal sensorial information.

These representations are also perceptually vehicled, because they rely on environmental cues, dependent upon information from the senses, as evidenced by the previous examples concerning anticipatory behavior, navigation and cross-modal sensorial information. And finally, these representations lack the constituent structure characteristic of propositional thought. I will expand on this characteristic in the next two sections, in which I describe the sensory-motor representations of the clocks as *metrically structured analog* representations. Provisionally, it suffices to characterize these representations as metric representations that lack the *syntactic* structure of propositional thought.[43]

The minimalist approach adequately captures some of the main characteristics of the outputs of the clocks. However, as Bermúdez acknowledges, the minimalist approach is not sufficient to give a complete account of nonlinguistic thought (2003, 62). Bermúdez focuses on two cases left out by the minimalist approach, i.e., the re-identification of particulars and instrumental beliefs in nonlinguistic creatures. But the minimalist approach *per se* is also insufficient to fully characterize the representational outputs of the clocks because it says nothing about their *structure*. It states that such structure must be non-propositional, but it does not go beyond this negative characterization.

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discussion of this issue see Matthews, R. J. (2007) and references therein.

[43] Actually, even this is questionable because it is not obvious that propositional thought *itself* has syntactic structure, although clearly representations of it do. See Matthews (2007) for the case against construing thought (specifically propositional attitudes) syntactically.

As mentioned, I will argue that a defining characteristic of these clock-representations is that they have metric structure, by which I mean that the computational characteristics that define these representations is such that it makes possible the calculation of a distance function. This distance function maps phases or intervals with circadian clock and stopwatch representations and it encodes and preserves distance information between such phases and intervals.

In the case of the circadian clock, information about the distance between two phases is preserved in memory for time of occurrence. In addition, the phase information of the circadian clock can also be used to compute spatial information, like in the case of the ephemeris function that gives the sun's azimuthal position. And with respect to the stopwatch, distance information about intervals is preserved to compare the durations of such intervals and to anticipate non-periodic events.

Another way of describing the metric structure of the outputs of the clocks is by analogizing them with measurements of temporal information. The measuring devices would be the clocks, one of which measures temporal information periodically, in terms of phases, and the other aperiodically, in terms of intervals. In order to be analogized with measurements, the outputs of the clocks must be somehow correlated with numbers. As Bertrand Russell (1937) says: "Measurement demands some one-one relation between the numbers and magnitudes in question—a relation which may be direct or indirect, important or trivial, according to circumstances."[44]

The clock-representations would have a direct and non-trivial mapping relation, since there are no *intermediate* magnitudes or measurements involved in the mapping between

[44] Russell, B. (1937), p. 176

periods and intervals and their representation by the clocks. But the introduction of numbers seems *prima facie* unwarranted. Not all clocks need a numeric counter to work properly and, in principle, none of them require a counter as a component to accurately measure time. It is the *user* of a clock that benefits from a counter, and the artificial introduction of numbers to analogize clock-representations to measurements might make the one-one relation, mentioned by Russell, trivial.

In the spirit of the minimalist approach, it would be desirable to avoid assigning more structure to the clock-representations than what is required to accurately define them. Particularly, it would be desirable to avoid over-assigning the relational structure of the real numbers to the structure of the outputs of the clocks. Eli Dresner (2004) defines this over-assignment of structure as: "the unwarranted assumption that every numeric relation holding among two (or more) numbers represents some empirical, physical relation among the objects to which these numbers are assigned as measures (e.g., of temperature)." (2004, 467) Dresner exemplifies the over-assignment of structure in the case of temperature as follows:

> Twenty is two times ten. The length of a body of 20 centimeters is twice the length of a 10-centimeter body. But is the temperature of a body at 20 Centigrade two times the temperature of a body at 10 Centigrade? No, it is not. This is easy to see by converting the temperatures into Fahrenheit: 20 Centigrade is 68 Fahrenheit, 10 Centigrade is 50 Fahrenheit, and thus the first temperature is no longer two times the other. As these are the same two temperatures that are being measured, each time in a different scale, we conclude that there is just no fact of the matter in temperature reality of one body's temperature being x times the temperature of the other. (Dresner, 2004, 467)

To think that the temperature of a room at 20 Centigrade is twice the temperature of a room at 10 Centigrade is equivalent to over-assigning the structure of these numbers to the structure of temperatures. The numbers (20 and 10) and the scale in Centigrade degrees, *measure* the temperatures in question. But a different *scale* will yield different numbers and a different relation among these numbers. There is, as Bertrand Russell demands, a one-one relation between the numbers and the magnitudes in question (temperatures). But different scales produce different numbers.

This is important to define the metric structure of the outputs of the clocks, because if the relations among numbers are not direct mappings of relations among phases of periods or segments of intervals that fully capture their structure, then the mapping relation determined by the distance function described above will be constitutive of a *homomorphism*, rather than an *isomorphism.* As Dresner says:

> What is required for measurement is only a *homomorphism* from the empirical structure to the mathematical one (i.e., the numbers), not an *isomorphism* between the two structures. That is, the empirical structure must be mapped into the mathematical one *but not necessarily the other way around*: there could be extra structure in the abstract mathematical entity that does not reflect anything in the empirical structure being measured. (Dresner, 2004, 470)

Homomorphism seems adequate to define the mapping between the metric structure of the output of the clocks and numbers. The user a clock might need numbers to measure periods or intervals, but the numbers do not reflect the structure of these periods or intervals. In other words, the counter has extra structure that does not reflect the structure of the periods and intervals.

The notion that the type of mapping relation required for measurement (and for mental representations that can be analogized with measurements) is a homomorphism receives support from the psychological literature. For example, Gallistel and King (2009) define representation in psychology in terms of homomorphism. They call these behaviorally relevant mappings constitutive of representations as a 'functioning homomorphism' because of its causal efficacy (2009, 70).

In general, it is true that measurements and mental representations that are analogous to measurements are best described as homomorphisms. However, in the specific case of periods and intervals, the mapping between numbers and the periods or intervals is actually an isomorphism. To defend this claim, I will first distinguish in more detail the difference between a homomorphism and an isomorphism and then explain why the mapping relation determined by the distance function of the clocks is constitutive of an isomorphism, which holds between periods and intervals and their representation by the clocks.

A homomorphism is a relation among structures: it is a one to one mapping between all the constituent objects of the represented structure to the objects of the representing structure, such that all the relations that exist among the objects of the represented structure are preserved among the objects of the representing structure. Thus, a homomorphism is a structure-preserving mapping. In the case of temperatures and numbers, the numbers preserve the order relation that exists among temperatures, which also preserves important mathematical properties, such as their compliance with the axioms of addition.

An isomorphism is a type of homomorphism: it is a *bijective* homomorphism, which means that the one to one mapping is symmetric and preserves the structure from the representing structure to the represented structure and vice versa. In the case of the temperature example, one instance of a relation dependent upon the structure of numbers (*being twice* the magnitude) surpasses the structure of temperatures and this is the reason why such a mapping is a homomorphism, rather than an isomorphism. If two structures are isomorphic then there is a two-way homomorphism, i.e., every structural relation among the constituents of each structure is preserved and both structures are identical.

The mapping between the phases of a cycle (the *represented* structure) and the numbers that mark the 360 degrees of a circle (the *representing* structure) is clearly a homomorphism because all the relations among the phases are preserved by the one to one mapping between phases and degrees. And the same is true about the segmentations of an interval and the numbers of a line. But are these mappings an isomorphism too, i.e., are the numeric structures of the circle and the line identical to the structures of periodic cycles and intervals? In both cases, the answer is affirmative.

The 360 degrees of a circle can be mapped to the phases of a periodic cycle and obtain the same structure without making under or over-assignments of structure. If this is true, then properties of the degrees of a circle must be identical to the properties of the phases of a periodic clock. I will give two examples of such cases of identity of structure in the circadian clock. First, the numbers 0 and 360 mark the same degree of the circle and this property is found in the circadian clock's concluding phase of a cycle, which marks also the beginning of a new cycle.

Second, in the case of addition, a sum of degrees that exceeds 360 degrees gives as a result a degree smaller than 360 degrees. In the case of the circadian clock, events happening beyond the cycle of 24 hours are represented as happening within that cycle, which is why the circadian clock's representations confound moments in time. For example, $180° + 360° = 180°$ (not $540°$). If a circadian clock is at phase 'noon' (half its cycle) and you isolate it for a whole cycle of 24 hours it will not shift: its next phase will be noon, which is structurally identical to the addition $180° + 360° = 180$.

The experiments I mentioned in the previous chapter exemplify other isomorphic properties between the circadian clock and the mathematical structure of the circle. Entrainment and other crucial characteristics of the clock are modeled after such structure. A consequence of the isomorphism that exists between the structure of periodic clocks (as well as their representations) and the circle is that all periodic clocks are structurally and functionally isomorphic.[45]

Interval clocks and their representations are isomorphic to the mathematical structure of a line.[46] The line is understood mathematically as the set of real numbers because of its *continuity* and *ordered structure*. The real line (the set of all real numbers) is a totally ordered set because given any two real numbers, either they are identical or one of them is bigger than the other. The real line can be represented as the interval $(-\infty,\infty)$.[47]

However, animals and humans with the capacity to represent intervals (based on the stopwatch) never experience open or infinite intervals.[48] Thus, the isomorphism between the line and an interval is best captured by a closed interval, such as [0,1]. The number 0 (it could actually be any number within a close interval) corresponds to time *t1*, which denotes the activation of the stopwatch. Similarly, the number 1 corresponds to time *t2*,

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[45] I say that the clocks (periodic and interval) and their *representations* are isomorphic to mathematical structures because these mechanisms represent (like any other clock) by *emulating* periods and intervals. Thus, what holds for the structure of the clocks holds for their representations.

[46] In mathematics, topological considerations complicate the definitions of 'point', 'line' and 'space'. However, the basic definitions of 'circle' and 'line' that I am using are the ones required to capture the structure of periodic and interval clocks.

[47] In chapter 5, I explain why the characterization of interval time representations as continuous (real numbers) or discrete (integer numbers) is relevant for the metaphysics of time, particularly with respect to the structure of the A and B series.

[48] Technically speaking, $(-\infty,\infty)$ is a closed interval, but this is issue is orthogonal to the discussion of the isomorphism between lines and the interval representations of the stopwatch.

which denotes the deactivation of the stopwatch. Intermediate numbers between 0 and 1 correspond to intermediate time-segments of the interval. The properties of the real numbers (continuity and order) are also present in the moments of an interval. As a consequence, all interval clocks are structurally isomorphic.

Historically, the isomorphism between intervals and the real numbers has played a very significant role in the development of mathematics. It is a central topic in the foundations of mathematics and some mathematicians have characterized our capacity to represent temporal intervals as the origin of mathematical thought. For example, L. E. J. Brouwer (1907) called our capacity to perceive time intervals as the basic intuition of mathematics.[49] As I mentioned in chapter 2, one of the advantages of interval timing is that it makes possible visualizations of time that capture our intuitive notion of time. These visualizations are constantly used in applied mathematics.

In summary, measurements are best described in terms of homomorphism: a structure preserving mapping that exists between an empirical structure and a mathematical one. But, in the specific case of periodic and interval timing, the mapping between these structures is an isomorphism. However, why are time measurements unique in this respect, i.e., what makes them different from other measurements? The answer is that time, like space, is a *primitive* magnitude. This means that time is a fundamental magnitude that cannot be decomposed into other magnitudes. In contrast, magnitudes like temperature or rate are derived from other, more fundamental ones. S. S. Stevens explains:

> The classical view of measurement […] is essentially the view that direct or "fundamental" measurement is possible only when the "axioms of additivity" can be

[49] The philosophical pedigree of this idea goes back to the work of Immanuel Kant.

> shown to be isomorphic with the manipulations we perform upon objects. Only a few properties, such as length, weight, and electric resistance, are measurable in this fundamental way. (Stevens, 1959, 22)[50]

One of these fundamental magnitude-properties is time, as measured by periodic and interval clocks. Many other magnitudes derive from time and its combination with other fundamental or derived magnitudes. Time combined with number produces rate; distance divided by time is speed, etc. S. S. Stevens, in his proposal for a theory of measurement that goes beyond the classical view by accommodating all forms of one to one correspondence between numbers and events or objects (not only magnitudes) according to a *rule*, proposes four fundamental scales: nominal, ordinal, interval and ratio (1959, 25). Of these scales, two of them (interval and ratio) correlate with timing, which demonstrates the primitiveness of measurements of time. In contrast, temperature and many other magnitudes are measured in different scales and depend on other, more fundamental magnitudes, such as mass, and density.

To recapitulate, in this section I defend a minimalist approach to the nonlinguistic representational outputs of the clocks in terms of isomorphism. Periodic clocks and their representations in terms of phase-dependent information are isomorphic to the mathematical structure of a circle. Interval clocks and their representations are isomorphic to the mathematical structure of a line. The numbers that mark the degrees of a circle and the real numbers of the line are necessary to characterize and manipulate

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[50] The words within the scare quotes in Steven's citation are references to N. R. Campbell's (1928) presentation of the classical view of measurement in physics, which is what Stevens is commenting on.

these structures, which solves the two fundamental problems of numerical measurement theory.[51]

It solves the *representation problem* because it justifies the assignment of numbers to phenomena (periods and intervals) by showing that the numeric structure of the circle and the line preserve the structure of the empirical systems in question (i.e., the representational outputs of the circadian clock and the stopwatch). And it solves the *uniqueness problem* because it specifies the degree to which the mapping between the numeric structure of circles and lines and periods and intervals is unique by demonstrating that it is isomorphic and independent of scale (unlike temperature or weight).

Since they are isomorphic, there is no over-assignment of structure by interpreting numeric relations as empirical facts about the clocks and their representations. In the next section, I discuss the implications of the metric structure of these representations, expand on the specific metric properties of periodic and interval clocks, and provide experimental evidence of their impact on the behavior of animals and humans.

3.3. Metric structure

In the previous section, I defined the metric structure of periodic and interval clock-representations as a computational feature of these representations that makes possible the calculation of a distance function, i.e., a mapping between environmental phases or intervals and clock representations that preserve distance information between such

[51] See Suppes, P. and Zinnes, J. (1967) for a clear presentation of measurement theory. See also Matthews, R. J. (1994) for a measurement theoretic account of propositional attitudes that addresses these problems.

phases and intervals. I shall now elaborate on this definition, emphasizing how it relates to the specific characteristics of the two types of clock representations.

The distance preserving function is a computation based on the two isomorphisms discussed in the previous section, which correspond to the functional structure of each clock. I will characterize only the *outputs* of the clocks as representations and will not delve into the controversial issue of whether or not the inputs should also be considered representations.[52] The purpose of the previous section was to give a definition of representation in terms of a nonlinguistic isomorphism that preserves distance relations, also known as an *isometric isomorphism*. This definition is meant to capture the specific characteristics of the clocks' representations and may not be adequate to define other representations.

The metric structure of the representations of the circadian clock and the stopwatch is framed by the specific characteristics of each clock, which were described in chapter 2. The advantages and disadvantages of each clock are manifest in the way in which the distance function is computed. I will first discuss the metric structure of the representational outputs of the circadian clock and then describe the representations of the stopwatch. In both cases, I will rely on experimental evidence.

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[52] The inputs of the circadian clock include signals concerning gene transcription, phototransduction, DNA to protein translation and hormonal cycles, among many other biochemical signals. The stopwatch's inputs include cross-modal sensory signals and complex neurological network activity necessary to emulate intervals. It would be inappropriate to characterize all these, very different signals, as representations. In any case, I will not provide such a characterization here, and focus exclusively on the outputs of the clocks.

3.3.1. The metric structure of the outputs of the circadian clock

In the previous chapter, I described experimental evidence that shows how the nervous system of insects, (bees in particular) is able to compute a solar ephemeris function using information from the circadian clock. More specifically, phase-information concerning the temporal cycle of the circadian clock is interpreted spatially, providing the animal with a direction to orient itself. This temporal phase-information of the circadian clock can be used for sun-compass navigation because it *continuously varies* with the angular positions of the sun as it moves across the sky. It is precisely because the circadian clock is a mechanism that updates its information continuously, that an isomorphism between the phases of the cycle of the rotation of the earth on its own axis and the phases of the cycle of the circadian clock can be established.

Evidence from experiments with ants further supports the notion that the information computed by the clock is continuously updated. For example, the distance function used for sun-compass navigation utilizes outputs of the circadian clock or “readings” of the clock that indicate its current phase, exploiting the isomorphism between the cycle of the circadian clock and the cycle of the rotation of the earth on its own axis. These readings appear as a variable in the function, which changes value according to the phase of the clock. In other words, the metric structure of the outputs of the circadian clock makes possible the computation of other metric representations, such as the calculation of the azimuthal position of the sun, because it provides a temporally framed *representation* *space* of possibilities based on phase-related information.[53] I proceed to explain the experimental evidence in more detail.

In the case of the desert ant *Cataglyphis fortis*, two hypotheses were tested to determine *how* they compute the solar ephemeris function. The extrapolation hypothesis postulates that the ant uses the most recent encoding of the position of the sun and then extrapolates its current position. In contrast, the interpolation hypothesis stipulates that the ant computes the ephemeris function by linearly interpolating memorized positions of the sun by *filling the gaps* of time where the ant had no environmental cues, using circadian clock information. Experiments in which ants were trained during the morning but tested at night with moonlight or artificial light confirm that they are *interpolating* the position of the sun based on information from their circadian clock (See Wehner, R. and Müller, R., 1993). These results have also been confirmed in the honeybee, as mentioned in the previous chapter. Moreover, Wehner and Müller showed that:

> If ants are restricted, from the very beginning of their outdoor activities, to forage only in the early morning hours and are later tested for the first time in the late afternoon, they expect the solar azimuth to have moved through about 180°. (Wehner and Müller, 1993, 333)

Wehner and Müller interpret this result as evidence that "*Cataglyphis* is informed innately about one general spatiotemporal aspect of the sun's 24-h course, namely, that the angular positions of the solar meridian at sunrise and sunset lie opposite to each other" (1993, 333). Regardless of how one interprets this result, it certainly confirms the automatic, self-sufficient nature of the circadian clock. Because of entrainment, the outputs of the circadian clock can be used for sun-compass navigation: they are

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[53] See Matthews, R. J. (1994) for an account of how representation spaces structured by metric mappings provide satisfaction conditions that allow for semantic evaluability and

constantly updated and preserve an isometric isomorphism with respect to the cycle of the rotation of the earth on its own axis in a very reliable manner, thereby providing a reliable representation space that can be interpreted in terms of location (i.e., the position of the sun).

The interpolation model assumes that the time of occurrence of certain cues that correlate with phases of the circadian clock are somehow encoded and used to calculate the solar ephemeris function. Otherwise, the ants could not compute this function, because they would have no phase information in memory to interpolate. As I explained in the previous chapter, memories for time of occurrence are very important circadian clock representations. In this subsection, I will briefly describe how these memories are registered through a process that is entirely dependent upon the metric structure of the circadian clock's representations.

Because oscillators have circular trajectories in a phase plane, they can be described by an angle or phase-angle. This is a very important characteristic of periodic clocks, discussed in the previous chapter, i.e., that they are always at a phase of their cycle. Based on the isomorphism between the cycle of the circadian clock and the structure of the circle, phases can be analogized with angles, and computations on angles can encode information about phases. If one represents such computations in a Cartesian coordinate system, one can graphically show that animals encode the time of occurrence of events based on readings of the circadian clock in terms of the sine and cosine of the phase. As C. R. Gallistel explains:

> The sine-cosine representation of angle as a function of time plots the values of the state variables as functions of time. When the maximum and minimum values of the

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inferential relations.

> variables are set equal to one, then these functions are the sine (*y*-variable) and cosine (*x*-variable) functions. By recording the momentary values of these variables, a system specifies a momentary state of the oscillator (a reading of the clock). This yields a specification of time unique up to a translation by an integer number of periods along the temporal axis. (Gallistel, 1990, 233)

These mathematical computations are possible because of the metric structure of the circadian clock's representations and they are the basis for the memory for time model I described in the previous chapter.[54] However, the *disadvantages* of periodic clocks affect the scope of these computations because the recording of moments in time in terms of sine and cosine can only distinguish moments within a period of 24 hours. As is the case with any other periodic clock, the circadian clock's representations confound moments in time that go beyond its cycle. It is possible, and actually quite probable, that some animals have the capacity to phase-relate *infradian* cycles to the circadian clock's cycle, which would allow them to distinguish moments beyond the period of 24 hours. This may depend on the lifespan of an animal. Animals with a very short lifespan may do very well without representations of time that go beyond the 24 hours cycle of the circadian clock. Other animals, like birds, may distinguish event that do not happen daily, but monthly. (See Gallistel 1990, 235)

Another important consideration, besides lifespan, is brainpower: the more complex the nervous system the more capacity for storing and manipulating outputs from the circadian clock. In any case, the memories for time, however computed, must be stored in the brain or nervous system of an animal. If an animal has a *semi-hybrid* clock that

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[54] If these memories of times are used to calculate an *interval* of time or if an interval clock is used to measure the durations between phases of the periodic clock, there is no *genuine combination of clocks*, as principle (PS) stipulates (see Chapter 2). The periodic clock's phases are not *determined* by intervals. Rather, the interval clocks are *used to measure* the duration of segments of the periodic clock's cycle.

registers circadian clock times analogously to a calendar, then distinguishing times from periods that are much longer than 24 hours would be a relatively easy task.[55] This seems to be the case with some birds from the corvid family, particularly scrub jays.

In an impressive series of experiments, Clayton, Dickinson and their collaborators (1998, 2003a, 2003b, 2006)[56] have shown that scrub jays have not only a semi-hybrid clock that allows them to organize temporal information in a calendar-like fashion, but that they also use such information to create a spatiotemporal representation of their caches that includes their location, rate of decomposition and whether or not other jays were looking when they made the cache. Gallistel (2008) summarizes the results from these experiments as follows:

> They [the scrub jays] remember what kind of prey they hid in each cache, when they made each cache, which other jay if any was watching when they made that cache, and whether they have subsequently emptied that cache. They also remember whether they themselves have pilfered the caches of another bird. They remember the intervals that have elapsed in the past between the hiding and retrieval of a given kind of food and whether the food, when retrieved had or had not rotten. (Gallistel, 2008, 236)

Regardless of how one characterizes the types of memories manifest in the scrub jay's behavior, it is clear that at a minimum this evidence suggests the existence of a very sophisticated type of memory.[57] The outputs of the clocks need not have such symbolic

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[55] For discussion on hybrid clocks and the principles governing them see chapter 2.

[56] The amazing memory capacity of the scrub jay allows them to represent complex cognitive maps for caches. Although scrub jays make more than *thirty thousand* different caches during their life, over vast areas of landscape, they retrieve one by one these caches during the days and months where food is scarce. See Vander Wall (1990).

[57] This is an observation frequently made by Gallistel with respect to this and other similar evidence in human and non-human organisms. Gallistel actually claims that the evidence demonstrates the existence of a symbolic read-write memory, similar to the memory of a computer. See also Gallistel and King (2009). I will remain neutral about this issue and only acknowledge that the evidence indeed demonstrates a highly sophisticated kind of memory in animals and humans.

structure and actually, in section 3.4, I will argue that the metric structure of the outputs of the clocks is in an analog, rather than digital, format. However, readings of the clocks by other regions of the brain, particularly regions that store information symbolically, will *interpret* and *store* the information from the clocks, thus creating a complex semi-hybrid clock.

Notice that even if distance functions that are not exclusively temporal, such as the ephemeris function, are computed by other symbolically driven regions of the brain, the *metric structure* of the outputs of the clocks, in this case the circadian clock, is what makes these computations *distance-preserving ones.* I shall now proceed to describe the metric structure of the outputs of the stopwatch.

3.3.2. The metric structure of the outputs of the stopwatch

In chapter 2, I mentioned that the scalar property of interval timing corresponds to the scale/resolution tradeoff, characteristic of interval clocks. What this means in terms of the distance function constitutive of the metric structure of the outputs of the stopwatch is that the computation of distance concerning intervals is limited by this tradeoff. I offered evidence that demonstrates how the stopwatch's degree of error in calculating intervals increases proportionally with the duration of the interval. In this section, I shall briefly describe how this metric property of keeping the degree of accuracy constant relies on the isometric isomorphism that exists between the outputs of the stopwatch and the intervals that they emulate.

As I mentioned in chapter 2, Gibbon (1977) presented the scalar timing theory in order to explain the scalar property of the stopwatch's interval timing. Evidence in support of scalar timing shows that there is a latency *difference* between the experienced intervals in which food (or other reward) is randomly given to the animal and the intervals between peaks of activity, which indicate that the animal expects food. The important discovery concerning the latency between, as Gibbon named them, the objective (external) and the subjective (internal) intervals, is that it is governed by a scalar factor. Gallistel describes one of the relevant findings, concerning a procedure with fixed intervals experienced by rats, as follows:

> The rat's peak response rate occurred at 24 seconds where there was a 20-second reward latency and at 48 seconds when there was a 40-second reward latency. In both cases, the peak, which is taken to indicate when the rat expects the food, occurs at an elapsed interval equal to the correct interval multiplied by 1.2. It is this finding (and numerous similar ones in other tasks) that leads to the term *scalar timing theory*. […] The model developed by Gibbon and his collaborators postulates that the remembered duration of an elapsed interval is its experienced duration multiplied by a scalar factor, which varies from animal to animal. (Gallistel, 1990, 301)

The value of the scalar, or multiplicative factor, may change from animal to animal, but it is always constant within an animal. Otherwise, the stopwatch would not be reliable. To illustrate this, imagine the following (somewhat idealized) scenario. Suppose that three people have to measure intervals, say the durations of different songs. They have a reliable sand clock, with a constant rate and numerically marked intervals, but each clock contains different sand materials, say carbon, granite and salt. Every time they stop the clock and measure an interval, they empty its content and dehydrate the sand material, compressing it into a small brick that they put into a container that classifies songs according to their numerical order.

Suppose that someone asks them, immediately after they compressed one of their measurements, to report the duration of that interval. They would add water and the sand would grow back to its original size, but given that the materials have different density, they might not grow back to their *exact* original size. However, as long as they always add the same amount of water, the sand would grow at a constant *ratio*. Thus, one of them would approximate the interval, say 1 minute, very closely: 1.01 minutes (a factor of 1.01). The other two measurements might not be as accurate, but they will not be far off target: 1.1 and 1.2 (factors of 1.1 and 1.2). Had they measured an interval of 2 minutes, they would have reported 2.02, 2.2 and 2.4 respectively. These numerical values differ, but they preserve the length of the original interval through a scalar factor and the distance function can be computed because of this metric feature of the structure of the outputs of the stopwatch.

Notice that the different scalar factors are not an artifice produced by the over-assignment of the numeric values of different *scales*, as is the case with Dresner's example of temperatures in the Celsius and Fahrenheit scales. Rather, it is a consequence of the *scale/resolution tradeoff* characteristic of all interval clocks, as the previous case exemplifies. If the interval is short, the resolution is good. But as intervals get larger, the resolution drops. If an interval has a duration of 20 minutes, the corresponding values of the three previous clock information-retrieving mechanisms will be: 20.2, 22 and 24. If an interval has a duration of 100 minutes, the values are 101, 110 and 120. 20 minutes seems to be a very large difference, compared to the 12 seconds of the first example (.2 minutes). However, the *degree* of accuracy is the same: 1.2, even though the accuracy of the clock drops as the duration of the interval grows.

The scalar property of interval timing illustrates a very important characteristic of the outputs of the clocks, besides their metric structure, i.e., that they are *approximate representations*. In the next section, I explain why this is one of the properties that makes the outputs of the clocks *analog* representations. I shall now emphasize how the scalar property of interval timing demonstrates that the isomorphism between the representing interval, which explicitly emulates an interval by an accumulation or decay process, and the represented interval, is *distance preserving*.

The scalar factor governing the outputs of the stopwatch is the basis for Weber's law in the temporal representation domain. But Weber's law also governs other kinds of magnitude-based representation, such as number and ratio. Since time is a primitive magnitude (it cannot be decomposed into other, more primitive magnitudes) preserving temporal metric relations is fundamental for computing other magnitudes. The case of the computation of the ephemeris function is one example, but the computation of rate and speed are other, equally relevant examples.

Weber's law is a ubiquitous feature of the *comparison* of magnitude representations in animals and humans.[58] It captures the scalar factor of interval timing, and it is expressed by the formula $\Delta I/I = k$. In words, the formula says that the difference threshold (ΔI), or minimal change required for *discrimination*, divided by the value of the initial stimulus or magnitude is constant (k). The value of (k)—the constant—has to be found through experiment because, as mentioned, this value, which is the scalar or multiplicative factor, varies from animal to animal.

The difference threshold is the value in which, because of the scalar factor, changes in value are not noticeable. This is why Weber's law is frequently explained in terms of "just noticeable differences." In the previous case of the interval with a duration of 100

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[58] Conformity to Weber's law has been reported in adult humans (Cordes, Gelman, Gallistel and Whalen, 2001; Moyer and Landeuer, 1967; Whalen, Gallistel and Gelman, 1999), infants (Xu and Spelke, 2000) and non-human animals (Cheng and Roberts, 1991; Church and Gibbon, 1982; Gibbon, 1977) both in the temporal and number domains.

minutes, the values were 101, 110 and 120. Weber's law determines that in the first case, the constant is 101-100, which is 1 (the difference threshold or ΔI). This value (i.e., 1) divided by 100 = is .01. The same formula applied to the other values result in .1 and .2, which are indeed the difference in error that is kept constant, plus the unit interval. This means that the multiplicative factors that are kept constant for these values are the original magnitudes' values, represented by 1, *plus* the scalar factor responsible for the difference threshold, which gives the correct values: 1.01, 1.1 and 1.2.

Weber's law captures the approximate nature of magnitude representations. For example, in the case where the interval is 100 minutes and the scalar factor, or degree of accuracy, is 1.2 the represented or retrieved interval will be 120 minutes. This means that the difference threshold is 20 minutes. Other represented intervals that are within this threshold, i.e., experienced intervals whose values lie between 101 and 119 minutes, will be considered as *equal in duration* by the creature whose scalar factor is 1.2, i.e., 100 minutes. This is what a constant degree of accuracy with a scalar factor of 1.2 means for 100 minutes intervals: there is no capacity to discriminate compared intervals that lie within the threshold.

As mentioned, Weber's law has been confirmed in the number and rate domains, in animals and humans. It applies to the noticeable differences in intensity of stimuli, differences in weight and sound, and also applies across the board with respect to magnitude-based representations. This confirms my previous assertion that the scalar factor responsible for the scalar variability of interval timing is not the result of an over-assignment of structure based on the numeric values of a scale to the metric structure of

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Conformity to Weber's law is considered as a signature of magnitude representations the outputs of the clock. Rather, it is one of the most critical *psychophysical laws* that govern the retrieval of information concerning isomorphic (in the case of time) or homomorphic mappings between stimuli and representations.

As in the case of the outputs of the circadian clock, the metric structure of the outputs of the stopwatch makes possible the computation of distance-preserving mathematical calculations. Through different experimental procedures, researchers have found that intervals can be *added* and *subtracted*, particularly in the so called "time-left" paradigm, in which an animal has to choose one of two options that will give a payoff in a particular amount of time. As Gallistel says,

> There is a very large body of evidence to the effect that animals routinely respond on the basis of temporal ratios, the ratio between the interval elapsed since the most recent occurrence of an event and a reference interval in memory. Thus the isomorphism between objective temporal intervals and the brain processes that adapt the animal's behavior to these temporal regularities is a rich one; it includes the operations of division and subtraction (in the time-left paradigm). (Gallistel, 1990, 315)

These temporal ratios, which are governed by Weber's law, are based on the metric structure of the outputs of the stopwatch, and they constitute the cornerstone of interval timing. These metrically structured representations make possible the formation of representation spaces that determine the options animals have and which course of action is the right one based on the lengths of the intervals they compare. For example, in the time left paradigm, the animal uses the metric information provided by the outputs of the stopwatch, plus information concerning rate stored in memory, to decide which of two options (pushing lever A or B) would produce a comparatively better reward, and are

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(See Gallistel and Gelman, 1992, and references therein for review).

incredibly accurate in performing this time sensitive task. And, as Gallistel says, the evidence in support of these metric features of interval timing is abundant.[59]

To conclude, the outputs of the circadian clock and the stopwatch are metrically structured. There are two independent systems for the representation of time, one for periods and the other for intervals, that have been confirmed to have metric properties in a vast number of experiments. However, it is important to determine how these metric temporal representations fit into a broader spectrum of mental representation. Some philosophers have categorized mental representations in terms of analog and digital computational formats. This distinction, which originated in engineering, is very useful to categorize the outputs of the clocks. In the next section, I explain why the outputs of the clocks are *analog representations* and provide an account of how they might interface with digital representations.

3.4. Analog clock-representations

The circadian clock outputs phase information that the brain uses for registering time of occurrence and, among other metric functions, the solar ephemeris function. The stopwatch outputs information concerning the duration of intervals (independently of

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[59] I mentioned in the previous chapter that there is an alternative model for interval timing that dispenses with the stopwatch, favored by Gallistel and King (2009). They base their objection against the stopwatch mainly on a theoretical difficulty they call "the problem of the first interval." They postulate a different model based on a read-write memory (a not entirely uncontroversial assumption) for interval timing dependent on oscillators that would work in terms of what I called, in chapter 2, periodic segmentation. I will not assess the merits of this alternative proposal because it is orthogonal to the main topic of this chapter, which is to describe the metric structure of interval and periodic *timing* regardless of the mechanisms involved. And I shall assume that the stopwatch is the mechanism responsible for interval timing because it is the most popular account among psychologists and the one that most intuitively makes sense of interval timing in terms of the accumulator model. Moreover, there are no differences between Gallistel and King's alternative model and the stopwatch with respect to experimental predictions.

phase information), which is also metrically structured. However, establishing the metric nature of these representations is not sufficient to determine *what kind* of representations the outputs of the clocks are. Of all the categories for mental representation that have been put forward in the philosophical literature, the distinction between analog and digital formats of representation is the most useful to classify the metric outputs of the clocks.[60]

I will use five criteria frequently used to characterize analog representation and argue that the outputs of the clocks satisfy all of the requirements imposed by these criteria. Of these criteria, only the first three apply distinctively to analog representation. The other two apply to representation in general, but they are of particular relevance for analog representation. The first criterion is that there is always loss of information in any analog to digital conversion, which means that analog representations contain more information than digital ones. The second is that the analog representations must be continuous or dense and the third is that they must be approximate. Finally, the fourth and fifth criteria are that *any* representation must allow for *misrepresentation* and also for *cognitive integration.*

Before proceeding, I shall mention an important caveat. It is easy to confound properties of the physical instantiation of a computational process with the *format* in which such process is computed. For example, it is frequently assumed that analog computation depends on continuous physical processes and that digital computation

[60] Philosophers have used the distinction between analog and digital as a means to distinguish conceptual from non-conceptual content. Although there is indeed a strong correlation between these distinctions, I will not argue for the conceptual or non-conceptual content of the outputs of the clocks, and present my characterization of such

depends on discrete ones. This assumption originates from the fact that analog computation manipulates signals and frequencies, physically instantiated by waves and charges that continuously vary their value. In contrast, digital systems of computation manipulate symbols with a particular meaning or value assignment.

When numbers are used to characterize analog processes, these processes are frequently represented by a continuous interval, say the real numbers that lie between 0 *to* 1, or [0, 1]. In contrast, digital processes are assigned the binary values 0 *or* 1. But notice, that these number assignments are not characterizing the *media* that instantiates a computational process. Rather, they are characterizing *how the information in the computational process is formatted* or how the user is *manipulating* the information.

In other words, the continuity of the real numbers is used to represent the continuous computational states of an analog computer and the discreteness of a string of numbers is used to represent the discrete computational steps of a digital computer.[61] The confusion stems from assuming that these properties (continuity and discreteness) are also properties of the media that instantiate the states of an analog or digital computer.

Some philosophers have noticed (e.g., Haugeland, J., 1998; and Lewis, D., 1971) that the distinction between analog and digital is problematic if applied to the media that instantiate a computational processes. To illustrate this point, one can count discrete numbers, and perform arithmetic operations on integers, by using discrete amounts of electric charges (a continuous medium). And one can perform approximate

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outputs only within the limits of the less controversial distinction between analog and digital.

[61] The continuity or discreteness of computational processes depends a lot on how time is represented. See C. Moore (1990, 1996) and Mycka and Costa (2007) and references

measurements of time by using a clock that instead of water uses pebbles (a discrete medium).[62]

The first computation is digital because each discrete amount of electricity is used as a symbolic stroke in a tally notion system and the second computation is analog because no individual pebble is used as a symbol. Thus, the distinction between analog and digital concerns formats of representation, not media. This clarification is very important because otherwise the notion of analog representation is doomed to be imprecise. And in order to achieve precision in defining analog representation, one must offer criteria that representations must satisfy in order to be characterized as analog. As Zenon Pylyshyn explains,

> Despite the existence of clear and easily understood cases of analog processes, and despite the frequent references made to this notion, it remains poorly understood. In particular, it has turned out to be extremely difficult to give an acceptable set of conditions for something being an analog. (Pylyshyn, 2007, 163)

Pylyshyn stresses the polysemy of the term ‘analog’ by indicating that he has used it to refer to any case where behavior is attributable to a fixed architecture (1984); Nelson Goodman (1976) and David Lewis (1971) have used it to characterize processes or representations with continuous properties; and Jerry Fodor (2007) has argued that analog representations have no canonical decompositions into semantically interpreted constituents. I submit that most of the polysemy and confusion originate from thinking that both medium (or vehicle) *and* representation must be continuous.

Having made this caveat and explained its importance, I shall now discuss the five criteria that define analog representations and show that all of these criteria are satisfied

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therein for discussion and potential applications of analog computation with a continuously represented time.

by the outputs of the circadian clock and the stopwatch. The main purpose of discussing these criteria is to give an accurate characterization of the outputs of the clocks. However, by contrasting these criteria with the defining criteria of digital or symbolic representation, and exemplifying their application in the case of temporal magnitudes, a secondary, but theoretically relevant goal of this section, is to provide the set of conditions that make a representation analog.

3.4.1. First criterion: loss of information

Fred Dretske (1981) has offered one of the most influential characterizations of analog and digital formats of representation. His account of analog representation highlights the loss of information that happens every time analog information is converted into digital information. This loss of information comports with the way in which digital devices perform *readings* on analog signals that contain more information than any particular digital computation or reading. As Dretske says,

> To describe a process in which a piece of information is converted form analog to digital form is to describe a process that necessarily involves the *loss* of information. Information is lost because we pass from a structure […] of greater informational content to one of lesser information content. (Dretske, 1981, 141)

Dretske illustrates this *loss-of information* principle with the way in which we linguistically communicate information about the content of pictures. Dretske notices that the content of the sentence 'the cup has coffee in it' is encoded in a picture of a cup with coffee in it. However, the picture contains much more information than the fact that there is coffee in a cup, e.g., *how dark* the coffee is, *how much* coffee is in the cup, what *color* and *shape* the cup has, etc. As Dretske says: "To say that a picture is worth a thousand words is merely to acknowledge that, for most pictures at least, the sentence needed to

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[62] This example is partly based on David Lewis (1971).

express all the information contained in the picture would have to be very complex indeed." (1981, 138) It is because of this loss of information from analog to digital, that Dretske proposes the following definitions:

> A signal (structure, event, state) carries the information that *s* is *F* in *digital* form if and only if the signal carries no additional information about *s*, no information that is not already nested in *s*'s being *F*. If the signal *does* carry additional information about *s*, information that is not nested in *s*'s being *F*, then I shall say that the signal carries this information in analog form. When a signal carries the information that *s* is *F* in analog form, the signal always carries more specific, more determinate, information about *s* than that it is *F*. (Dretske, 1981, 136)

Notice that Dretske's definitions are neutral as to the kind of medium that instantiates a cognitive process, and focus on the format in which information is processed, which avoids the confusion mentioned before between media and formats. A consequence of Dretske's definitions is that analog information will always carry some kind of digital information, at least potentially. Decoding digital information form an analog signal will require a specific *filter*.

In the case of the circadian clock, the readings of the clock performed to compute the solar ephemeris function and the time of occurrence of an event have less *temporal* information than the output of the clock. For instance, both readings lack temporal information concerning periodicity, phase fixed relationships with ultradian and infradian cycles, how much of the circadian cycle has been completed, etc. All this information is explicitly represented by the outputs of the circadian clock. And in the case of the stopwatch, information stored in memory concerning the comparison of short intervals may lack information concerning the specific length of intervals and the rate at which the stopwatch was operating (information explicitly represented by the outputs of the stopwatch).

The criterion of loss of information suits well the outputs of the clocks: temporal information is lost when it is converted from the analog outputs of the clocks to other, more specific and digital computations in the brain.[63] However, before proceeding with the other criteria, it is useful to make a distinction, proposed by R. Cummins, et al (2001). The relevant question one should ask in order to appreciate the importance of this distinction is: how should we categorize computational processes that systematically *recover* information that was lost in the analog to digital conversion?

Cummins, et al (2001) distinguish between structural encodings, pure encodings and structural representations. Structural representations are isomorphic to the structure that they represent—as is the case with the circadian clock and the stopwatch's outputs: they are isomorphic to the structure of the period of the rotation of the earth on its own axis and to the structure of the intervals emulated by the stopwatch.[64] Structural encodings are not isomorphic or even homomorphic to what they represent, but one can recover the structure of what is represented through some computational process.[65] Finally, a pure encoding is a symbolic representation that is not isomorphic or homomorphic to what it represents and from which it is impossible to recover the structure of what is represented.

Dretske's criterion of loss of information from analog to digital conversion holds for both cases of *encoding*, as defined by Cummins, et al. In the case of pure encodings, the

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[63] Computer models that describe how the brain can rapidly update complex information in a stable fashion suggest that the anatomy of the brain allows for a hybrid, analog and digital system of computation. For example, Randall C. O'Reilly (2006, 91) suggests that the prefrontal cortex has a discrete, digital character, while the rest of the cortex operates in an analog fashion.
[64] I described the mathematical aspects of these isomorphisms in section 3.2 of this chapter.
[65] The distinction between structural representations and encodings was originally introduced by R. Cummins (1996).

loss of information is quite significant: all information concerning structure is lost and cannot be recovered. And in the case of structural encodings, some information about structure might be recovered, but it would be extremely inefficient (for the brain or any other computational device) to recover *all* the structural information, because it would have been more economic not to convert it to digital information in the first place.

But even if such unparsimonious algorithms were accepted in a model, the only result is that the fully recovered structure would entail that the representation is really a structural representation and *not* a structural encoding, because it would be isomorphic to what it represents. Thus, structural encodings only account for partial recovery of structural information, and Dretske's criterion of loss of information from analog to digital conversion holds for both cases of encoding.[66]

3.4.2. Second criterion: continuity and density

Historically, in the development of computer science, the criterion of continuity and density was the most important one to distinguish analog from digital formats. The basis of the distinction is that computations that are analog vary their value assignments continuously, in a pattern that can be modeled as a continuous interval of values [0, 1]. In contrast, digital computations have either fixed value assignments or a very limited set of possible value assignments (e.g., either 0 or 1) and need to be modeled discretely, as a set or string of symbols.

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[66] James Blachowicz (1997) says that analog representation is constrained by resemblance. The type of isomorphism required for the *model-approach* to analog representation that he defends comports with the isomorphism that exists between the outputs of the clocks and what they represent, and it is also compatible with Cummins' et al. notion of structural representation.

Continuity and density have also been relevant for philosophical accounts of analog representation. For example, Nelson Goodman (1976) characterizes analog representation as syntactically and semantically dense. He explains that a representation is syntactically dense "if it provides for infinitely many characters so ordered that between each two there is a third." (1976, 136) Semantic density is a consequence of syntactic density, and it consists in the impossibility of assigning differentiated and unambiguous values to discrete symbols.

As Goodman notices, density does not imply continuity, because although the rational numbers are dense, according to the definition just given, there are "gaps" between them. This is the reason why discreteness is a necessary, but not sufficient condition for digital representation. Goodman submits that what is required for digital representation is *differentiation*, not mere discreteness.[67] Thus, according to Goodman, there can be analog representations that are not continuous. However, in the case of the outputs of the clocks, I will argue that these representations are dense *and* continuous, i.e., without gaps. Consider the following case of analog representation, offered by Dretske:

> The speedometer on an automobile constitutes an analog encoding of information about the vehicle's speed because different speeds are represented by different positions of the pointer. The position of the pointer is (more or less) continuously variable, and each of its different positions represents a different value for the quantity being represented. (Dretske, 1981, 135)

[67] Differentiation, in computational terms, requires individuation conditions for *symbols*. These individuation conditions, in turn, demand the existence of a program that individuates symbols according to their computational role. The lack of individuation conditions for symbols in analog representation entails the lack of symbolic constituents of more complex, syntactically structured representations. And the lack of syntactically structured representations entails the lack of canonical compositions and decompositions, which comports with Fodor's (2007) recent characterization of analog representation.

The representation of speed provided by the speedometer is a representation of the speed of the automobile, which is a continuous magnitude. If the pointer of the speedometer feeds its information into a digital register at a particular time, the digital numeric symbol for the speed of the automobile *at that time* would be displayed. But the speedometer and the pointer are representing the automobile's speed *continuously*. Speed is a continuous magnitude that is isomorphic to the real numbers because there are no gaps between speeds.[68] The speedometer represents the continuity of speed by means of the smooth transition of its pointer across the continuous surface in which a range of speeds is represented. And, as mentioned previously, this is not a matter of whether the medium is physically continuous. Rather, it is a matter of how speed is being represented.[69]

Similarly, the circadian clock continuously (without gaps) varies its phases in order to represent and emulate the period in which the earth rotates on its own axis. Each phase of the circadian cycle is like a position of the continuous surface of the speedometer, and readings of the circadian clock are equivalent to readings of the pointer of a speedometer. Similar considerations apply to the stopwatch: each segment of the interval emulated by the stopwatch is like a position of the speedometer and there are no gaps between

[68] The isomorphism between speed, time and the real numbers was a major factor in the development of the calculus, created to a large extent for the purpose of calculating instantaneous velocities on the basis of the continuity of these magnitudes.

[69] The continuity of the analog representations of the clocks (which can understood in terms of an isomorphism with the real numbers because there are no gaps between real numbers) does not entail that these representations exploit *all* the mathematical properties and relations definable on the real numbers. In particular, there are no infinite phase or segment "spaces" (an issue I addressed previously by stipulating that intervals of time are best understood as closed intervals). What it means is that, like the real numbers, the outputs of the clocks are continuous because there are no gaps between phases and

segments of intervals. The isomorphism between the outputs of the clocks and what they represent is a systematic and continuous mapping that, as explained in section 3.3, makes possible the preservation of the metric structure of periods and intervals. I shall now proceed with the third criterion that analog representations must satisfy: their approximate nature.

3.4.3. Third criterion: approximate representation

The third criterion that analog representations must satisfy is a consequence of the first two criteria because the richness of the information and the lack of symbolically differentiated value assignments characteristic of analog representation imply that analog representations *represent by approximation*. In the case of the outputs of the clocks, their rich metric structure and their density and continuity imply that these representations approximate the structure of periods and intervals by emulating them. As I explained in chapter 2, emulating periods and intervals depends on several factors. The variability of these factors may jeopardize the degree of precision with which periods and intervals are approximately emulated, e.g., *phase-drifts* in the case of the circadian clock and *variations in rate* in the case of the stopwatch.

John Haugeland (1981) distinguishes analog from digital representations in terms of approximation. He says that digital devices (or systems of representation) are defined by the following four features: a) a set of types; b) a set of feasible procedures for writing and reading tokens of those types; c) a specification of suitable operation conditions, such that, d) under those conditions, the procedures for the write-read cycle are positive and reliable. (1981, 216) Haugeland says that a procedure is *positive* just in case it can

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segments of an interval. See Matthews (1994) for a clear treatment of this issue in the succeed absolutely and without qualification and *reliable* just in case, under suitable conditions, it succeeds virtually every time (1981, 215).

In contrast, Haugeland argues, analog devices (or systems of representation) are defined by approximate read-write cycles, or approximation procedures that occur within certain margins of error, such that: a) the smaller the margin of error, the harder it is to stay within it; b) available procedures can *reliably* stay within small margins of error and c) there is no limit as to how small the margin of error could be, but it will never be zero: perfect or *positive* procedures are not possible. (1981, 221)

If we interpret the "read-write cycles" Haugeland mentions, as the *isomorphic mapping* from the period of the rotation of the earth on its own axis to the cycle of the circadian clock and from elapsed intervals to the emulated intervals of the stopwatch, then his definition of analog representational devices accurately captures crucial characteristics of these clocks and their representations. For example, the circadian clock can reliably, under suitable conditions, emulate the period of the rotation of the earth on its own axis within small margins of error (property 'b' of Haugeland's definition). However, if the standard for the margin of error is extremely small, the accuracy of the circadian clock will drop significantly (property 'a').

Suppose that some animals evolved incredibly accurate circadian clocks. No matter how accurate these clocks are their margin of error will never be zero (property 'c'), because they ultimately depend upon environmental conditions that change with the seasons and the latitude at which the animal lives. Adjustments to these variations require *approximation* procedures, as has been consistently demonstrated by phase-drift

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context of points in a representation space.

experiments in which an animal's circadian clock takes days to "catch-up" with the new daily cycle. In more colloquial and experiential terms, one does not eliminate the experience of being jet lagged after traveling across several time zones by computing a symbolic function. Rather, the circadian clock has to accelerate its pace and approximate the new daily cycle by shifting its phases.

Likewise, the stopwatch's outputs seem to be tailored to comply with Haugeland's criteria. Weber's law guarantees that the margin of error will never be zero, although it will be constant in proportion to the interval, which (in addition to the stopwatch's constant rate) guarantees the stopwatch's reliability. Moreover, it is a *fundamental characteristic* of interval clocks that their accuracy decreases as the magnitude of the interval increases, which gives further support to the approximate nature of the outputs of the stopwatch.

From a purely theoretical perspective, the first feature of analog representations mentioned by Haugeland, i.e., that the smaller the margin of error, the harder it is to stay within it, assumes continuity and density. For example, if the margin of error is determined in minutes one can make it smaller and determine it in seconds, and then in milliseconds, and even picoseconds. In principle, one can go even further beyond picoseconds because of the continuity of temporal magnitudes, which other magnitudes share. As mentioned, the outputs of the clocks are continuous and dense. A feature based on *ratio* (at least in the case of time), such as 'the smaller the margin of error, the harder to stay within it' assumes continuity and density because the process of reducing the margin of error is in principle unbound. This comports with the features of the outputs of the circadian clock and the stopwatch.

3.4.4. Fourth criterion: analog misrepresentation

Bermúdez (1995) argues that there are four criteria that any physical state must satisfy in order for it to be properly described as a *representational* state. These criteria for representational states are: a) they should serve to explain behavior in situations where the connections between sensory input and behavioral output cannot be plotted in law-like manner; b) they should admit of cognitive integration; c) they should be compositionally structured in such a way that their elements can be constituents of other representational states and d) they should permit the possibility of misrepresentation. (1995, 350)

Of the four criteria, only b) and d) are relevant for the characterization of the outputs of the clocks. I will not discuss criterion a) because defining what 'law-like' means is a very challenging task and actually, it is one of the central issues in the philosophy of science.[70] Trying to define what 'law-like' means requires assumptions concerning the existence of natural laws and their criteria for individuation. Giving an account of these criteria would be distracting and unproductive, because the task at hand is characterizing the representational outputs of the circadian clock and the stopwatch, not giving an account of 'law-likelihood'.

And criterion c) is inadequate for the present purposes because it is too restrictive: it assumes that representations must be syntactically structured by atomic symbolic constituents, which does not capture the main characteristics of the outputs of the circadian clock and the stopwatch, i.e., metric structure and analog representation. I will discuss criterion d) in this subsection and then criterion b) in subsection 3.4.5.

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[70] See for example Giere, R. (1999) and van Fraassen, B. (1989)

Criterion d), which demands that representational states should allow for the possibility of misrepresentation is not specific to analog representation and seems to be a necessary condition for any type of representation. But it is particularly problematic for analog representations to satisfy this criterion, specifically in the case of the outputs of the clocks, which are defined in terms of isomorphism. By preserving metric structure through isomorphism, the outputs of the clocks emulate reliably periods and intervals. However, by doing so, they also significantly reduce the possibility of misrepresenting such periods and intervals. An example discussed by Bermúdez, which actually concerns a representation produced by a periodic clock (tree rings) nicely illustrates this point:

> It would seem that a correctness condition can be provided, such as "the rings on the tree correctly indicate the age of the tree if, and only if, the number of rings = the number of years the tree has been in existence." But would these be *genuine* correctness conditions? Many would think not. They might argue as follows. No state could count as a representational state unless it was possible for it to *misrepresent* the environment. But it is the law-like connection between, for example, the number of rings and the number of years that makes it plausible to speak of the former carrying information about the latter, and what makes it a law-like connection is the fact that the number of rings and the number of years invariably coincide. Such invariable coincidence, however, clearly rules out the possibility of misrepresentation. (Bermúdez, 1995, 344-345)

Setting aside Bermúdez's assessment of tree rings in terms of 'law-likelihood', if one replaces 'law-like connection' with 'isomorphism' one can similarly argue that the possibility of misrepresentation in the case of the outputs of the clocks is ruled out. The main point of Bermúdez's contention is that if tree rings *invariably coincide* with numbers of years, then how could they possibly misrepresent information about years? This is a particularly pressing objection against the isomorphic representations that constitute the outputs of the clocks, because if they invariably coincide with metric features of periods and intervals, then how could they possibly misrepresent such periods and intervals?

In chapter 2, I argued that tree rings are registers of a periodic clock, i.e., the rotation of the earth around the sun. But these are registers of information that humans have to interpret, and interpretations can clearly misrepresent. The tree registers environmental changes that invariably coincide with the period of the rotation of the earth around the sun. But the tree has no access to this information. In contrasts, animals with hybrid-clocks, like the scrub jay, that register time of occurrence in their brain, have access to temporal information stored in their memory. For these reasons, it is problematic to call tree rings 'representations' without these qualifications.

Nonetheless, Bermúdez is right in claiming that a representational state must allow for the possibility of misrepresentation. Is there a way in which the outputs of the clocks could, in spite of their isomorphism with periods and intervals, allow for misrepresentation? The answer is that there are indeed ways in which the outputs of the clocks may misrepresent, and explaining them requires a characterization of the clocks as subpersonal information-processing mechanisms. For the purposes of the topic of misrepresentation, it suffices to say that the clocks are subpersonal information processing mechanisms because they operate in an automatic, causally driven fashion.

As is the case with any other subpersonal-information states, the information contained in the outputs of the clocks can be described teleologically.[71] Although my account of the outputs of the clocks does not require a fully articulated theory of teleological content, a few remarks regarding how the information of the clocks may be used by an animal or a human to obtain information *about relational-environmental properties* suffices to demonstrate that the clocks' information can misrepresent. I proceed to justify this claim.

Bermúdez explains how subpersonal information, like the one contained in the outputs of the clocks, can misrepresent in spite of the invariable coincidence that exists between representing and represented structures. His explanation relies on a constraint postulated by Christopher Peacocke, called the 'Overarching Constraint'. This constraint determines a condition that subpersonal information must satisfy in order to have content. One of the advantages of this constraint is that considerations about personal-level intentionality or personal identity can be set aside, which makes the attribution of content to subpersonal information states much more manageable. According to Peacocke, the 'Overarching Constraint' determines that:

> Correct ascriptions of content to subpersonal states are answerable to facts about the relational (environmental) properties of the events they explain, and to counterfactuals about the relational properties of the events they would explain in various counterfactual circumstances. (Peacocke, 1994, 312)

In the case of the circadian clock, its phases are answerable to facts about the properties of the period of the rotation of the earth on its own axis and to properties concerning the trajectory of the sun. Moreover, because of the mechanisms for phase-locking and fixing phase relationships, they are also answerable to daily environmental periodic events that are crucial for the animal's survival, as demonstrated by the experiments on time of occurrence discussed in chapter 2. The phases of the circadian

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[71] See Millikan, R. (1984) and McGinn, C. (1989) for teleological theories of content for subpersonal information.

clock are also answerable to counterfactuals, such as those concerning the theoretical hypotheses about entrainment and phase-drift, also discussed in chapter 2.

Similarly, the stopwatch's outputs are answerable to facts about properties of the environmental intervals that they emulate. The metric structure of these outputs allows the animal to predict events, as demonstrated by anticipatory feeding behavior. The constant rate of the stopwatch can be biochemically accelerated or decelerated, which explains various counterfactual circumstances that are experimentally testable, in which anticipatory behavior of environmental events becomes predictably less accurate.

However, the most important aspect of the relation between the outputs of the clocks and the environmental properties that they represent is that the clocks were *evolutionarily designed* to emulate and represent features of the period of the earth's rotation on its own axis and the duration of intervals of aperiodic events that play a crucial role in an animal's survival strategies. In contrast, tree rings *were not evolutionarily designed* to keep track of the period of the rotation of the earth around the sun. Tree rings *accidentally* happen to register such periods by growing in environments were seasonal changes alter the biochemical composition of the tree.

Counterfactuals are very relevant with respect to this issue. Consider the following hypothetical scenario: suppose you isolate the information processing mechanism from the environment. As demonstrated consistently in laboratories, if you isolate an animal from environmental cues its circadian clock would run free, reproducing the period of the rotation of the earth on its own axis. This is because the evolutionary purpose of the circadian clock is precisely to reproduce such a period. However, tree rings cannot be produced in isolation, i.e., they fully depend on the *combination* of atmospheric conditions that lead to tree ring formation and the growth of the tree. Thus, tree rings are as much a feature of the environment as they are a feature of the tree. This is why tree rings are so helpful to study ancient climates. The counterfactual situation of isolating a tree to test if its annual clock would run free is simply nonsensical.

Considerations of evolutionary design are very pertinent to teleological explanations of content, which are the basis for the possibility of misrepresentation in subpersonal information processing. Once the functions of the circadian clock and the stopwatch are experimentally identified as specifying features of the environment that the clocks were evolutionarily designed to emulate, a notion of *proper function* can explain how the clocks may misrepresent. As Bermúdez says,

> Given the particular features that a processing mechanism has been "designed" or "selected" to detect, it is functioning correctly when it responds appropriately to the presence of those features, and incorrectly when it responds in their absence. Correctness conditions are fixed with reference to evolutionary design and past performance. (Bermúdez, 1995, 367)

The challenge of demonstrating that the analog representations of the clocks can misrepresent can now be met. Unlike tree rings, the circadian clock and the stopwatch were evolutionarily designed to emulate the period of the earth's rotation on its own axis, and aperiodic intervals of important events. The clocks work *correctly* and represent appropriately temporal features when the phases of the circadian clock are locked to the appropriate environmental cues and when the rate of the stopwatch is constant. They misrepresent when the circadian clock free-runs or phase-drifts and when the stopwatch's rate varies. In these cases, the clocks do not invariably (isomorphically) respond to the particular features of the environment that they were designed to respond. I shall now proceed to explain how the outputs of the clocks admit of cognitive integration.

3.4.5. Fifth criterion: cognitive integration

As I mentioned in chapter 2, the circadian clock and the stopwatch were evolutionary designed for different purposes. In this chapter, I have argued that both mechanisms produce outputs with metric structure that are best captured in terms of analog representation. The circadian clock and the stopwatch are two different systems for temporal representation, each with its own type of isomorphism. However, the ubiquitous presence of the circadian clock throughout the spectrum of living organisms puts into question whether the circadian clock is really a representational mechanism.

An objection against the representational capacities of the circadian clock could be formulated as follows. What is the status of the outputs of the circadian clocks of plants and bacteria? They seem to have a *proper function*, which comports with teleological accounts of content and misrepresentation. The circadian clocks of plants and bacteria work correctly when they respond to the presence of sunlight and other environmentally relevant features and they work incorrectly in their absence, e.g., when they free-run. So, are plants and bacteria *representing* metric temporal features periodically?

This objection shows that analog misrepresentation is a necessary, but insufficient condition for *analog representation*. Besides the other three criteria (plus analog misrepresentation) another criterion, mentioned by Bermúdez, must be satisfied: the outputs of the circadian clock and the stopwatch should admit of cognitive integration. But defining what 'cognitive integration' means in the context of sensory-motor mechanisms, such as the circadian clock and the stopwatch, demands two qualifications. The first qualification is that cognitive integration does not necessarily require syntactic structure. As long as there is some type of representational structure, such as *metric structure*, cognitive integration can occur at the subpersonal level. Bermúdez explains,

> Cognitive integration requires structure, and there seem to be two principal criteria for the presence of structural representational states. First, they must be built up out of components which can be recombined to generate new representational states. Second, the process governing transitions between representational states must be sensitive to their composite structure. (Bermúdez, 1995, 365)

As mentioned, symbolic discreteness is not applicable to the outputs of the clocks. However, both criteria mentioned by Bermúdez are satisfied by the outputs of the clocks in an analog-metric fashion. For instance, with respect to the first criterion, the outputs of the circadian clock can be combined with spatial representations in order to compute the solar ephemeris function and the outputs of the stopwatch can be combined with numeric representations to compute rate.

With respect to the second criterion, the metric outputs of the clocks can be stored in memory and be used to register time of occurrence. These memories preserve the metric structure of the outputs of the clocks. Moreover, processes of re-phasing and comparing the duration of intervals, which could be considered as transitions between representational states of the clocks, preserve the isomorphism between temporal representations and the represented periods and intervals. Thus, the metric structure of the outputs of the clocks (and their approximate nature, which is manifest in Weber's law) constitutes a *common code* for computing not only temporal information, but also spatial and numeric information.[72]

The second qualification is that cognitive integration is an empirical issue that needs to be confirmed by experimental evidence. In the case of the circadian clock and the stopwatch there is plenty of evidence in support of cognitive integration. Since I have covered this material in chapter 2, I will not go through it again. I will just stress how important the representations of the circadian clock and the stopwatch are for the *sensory-motor system as a whole* by quoting Warren Meck, who says,

> Humans and other animals engage in a startlingly diverse array of behaviors that depends critically on the time of day or the ability to time short intervals. Timing intervals on the scale of many hours to around a day are mediated by the circadian timing mechanism, while in the range of seconds to minutes a different system, known as interval timing, is used. The term *interval timing* is used to describe the temporal discrimination processes involved in the estimation and reproduction of relatively short durations in the seconds-to-minutes range that form the fabric of our everyday existence and unite our mental representations of action sequences and rhythmical structures. (Meck, 2003, xvii)

The circadian clock and the stopwatch, as Meck says, are not only critically involved in a startlingly diverse array of behaviors, but they are also critical to *integrate a vast array of information*. Thus, the outputs of the clocks in animals and humans comply with the cognitive integration requirement and, actually, a significant amount of sensory-motor information integration *depends* on these clocks. With respect to the issue of analog to digital conversion, as long as the *relevant* metric structure is preserved, even though temporal information is lost (Dretske's criterion), metric cognitive integration can include symbolic computations from other areas of the brain by interfacing with metric-analog ones, which is presumably how the ephemeris function is computed.

More importantly, cognitive integration shows that the outputs of the circadian clock and stopwatch of animals are representations with *content* because they can be used and interpreted by the agent in a way that *information from the environment contained in these outputs successfully guides the agent*. In the computation of the ephemeris function,

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[72] For evidence on this common code framed by Weber's law see Dehaene, S. (1997) and

it is the metric mapping of the circadian clock with the period of the rotation of the earth on its own axis that successfully guides the agent toward the fulfillment of multiple goals. It is this metric mapping that gives content to the spatial representation of the position of the sun because it successfully maps to features of the environment.

This also reveals that there is a fairly direct way of interpreting information from the outputs of the clocks via a function that maps phases of periods or segments of represented intervals with other metric features, such as spatial positions and representations of number.[73] There is absolutely no evidence that plants *use* or *interpret* information from their circadian clock in this way (maybe because they lack a complex nervous system). This difference is what makes the outputs of the clocks of animals and humans representations with content.

To conclude, I take the five criteria I discussed in this section to be necessary conditions for analog representation *only in the specific cases of the outputs of the clocks*. Certainly, other weaker and more flexible versions of analog representation are possible. For instance, Blachowicz (1997) says that only relational identity (by which he means some sort of isomorphism) and qualitative or quantitative resemblance are necessary conditions for analog representation, and that continuity or density are not necessary conditions for analog representation. This more flexible account might suit well other analog representations, such as those on which Blachowicz focuses, i.e., maps and

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Gallistel, C. R. (1990)

[73] See Egan, F. (1995) for an explanation of the importance of interpretation-functions for determining the content of computations. See Millikan (1993) for how representations that lead to successful behavior can be given a 'consumer semantics' account of their content.

pictures. But this weaker definition does not suit well, as I have argued, the outputs of the clocks.

The five criteria I discussed in this section are critical to define the analog representations produced by the circadian clock and the stopwatch. However, one important problem remains to be solved: how does an agent know that a state of the phase of the clock or a segment of an interval is happening *now*. The representations of the circadian clock and the stopwatch are insufficient to solve this problem. A different type of representation, computed by a different mechanism must be in place. These other sensory-motor representations of time do not have as their main function the preservation of the metric structure of periods and intervals. Rather, their main function is to locate the agent in a temporal phase or segment of a represented interval. In other words, these representations constitute the *present*, which is the main topic of the next chapter.

Chapter 4

A Two-Phase Model of The Present

4.1. Introduction

Philosophers have claimed that the present has a special status and have also debated about its nature, such as whether it has duration. A central question is how should the special status of the present (whatever its nature) be understood? Some philosophers argue that it should be understood in psychological terms, i.e., that the present has a privileged cognitive status, but that it lacks a metaphysically privileged status.[74] Others say that the special status of the present is metaphysical, i.e., that there are objective facts about the present, which explain its unique status.[75]

I will not try to settle this issue here.[76] Rather, I shall assume that, at the very least, the present *appears* or *seems* to have a special status. We experience the present in a unique, and perhaps conceptually fundamental fashion—regardless of whether or not this uniqueness is justified from the perspective of metaphysics. What gives rise to our experience(s) of the present? What in our *cognitive constitution* explains this central role of the present in our experience? And what gives rise to the sense that the phenomenal present has duration?

These are questions that can best be answered with the help of cognitive science, which is how I shall try to answer them. In this chapter, I postulate a novel *two-phase* model of the present, which offers solutions to philosophical problems regarding the

[74] See for instance Smart, J. J. C. (1963, 1980, 2006), Le Poidevin, R. (2007) and Callender, C. (2008a).
[75] See for instance Chisholm, R. (1990), Prior, A. N. (2003) and Zimmerman, D. (2005).
[76] However, in the next chapter I will discuss some consequences of the model of the present I offer in this chapter for issues in the metaphysics of time.

present and is entirely based on experimental evidence. The model I defend also accounts for how the present relates to the outputs of the clocks. In terms of mental representation, the present moment needs to be associated with a *sensory-motor* mechanism, which interacts with the clocks. Action coordination, the manipulation of information coming from the clocks and basically any form of interaction with the environment requires that a particular phase of the circadian clock or a specific moment of an interval be marked by the mental equivalent of the indexical 'now'. Performing this *indexing* is the task of a sensory-motor mechanism that works independently from the clocks. Certainly, this sensory-motor mechanism is one of the most primitive and fundamental components of the sensory-motor system and I will describe its main characteristics in this chapter.

The evidence I review directly addresses traditional philosophical controversies concerning the present, such as: does it have duration? If so, what kind of structure does it have? What is the relationship between the indexical 'now' and the phenomenal present (i.e., the experienced present)? What is the best way to account for the alleged unity and continuity of the phenomenal present? These questions are answered with innovative proposals, the most important of which is the distinction between two types of present, with two different temporal phases or cognitive stages (hence the name of the model). My main focus in this chapter is the role of the present in the *representation* of time. In the next chapter I describe the implications of my account for the metaphysics of time.

The structure of this chapter is as follows. In section 4.2, I review the psychological evidence on simultaneity windows. Its main conclusion is the postulation of the first component of the two-phase model of the present: the sensorial-specious preset. In section 4.3, I describe the main cognitive function of the sensorial-specious present, which is to anchor the outputs of the clocks. In section 4.4, I discuss the main philosophical issues concerning the phenomenal present, review the experimental evidence on the phenomenal present and conclude by postulating the second component of the two-phase model: the phenomenal-specious present. Finally, in section 4.5, I outline the main characteristics of the two-phase model in more detail.

4.2. Simultaneity windows

One of the most important and robust psychological findings concerning the present is that there is a measurable amount of time during which stimuli are *judged (or registered) as simultaneously present* by the sensory-motor system, even though there is an interval separating the stimuli.[77] As I explain in the following subsection, this amount of time, called a 'simultaneity window', varies across modalities and depends on several factors, including age and specific properties of the stimuli. But before describing these and other interesting aspects of simultaneity windows, I shall briefly explain their relationship to the clocks.

The circadian clock and the stopwatch are extremely efficient registers of temporal information in terms of phases of periods and segments of intervals. However, the simultaneity of sense stimuli needs to be established *previously*, in order for the clocks to

[77] I will use the term 'judged simultaneity' instead of the more common term 'perceived simultaneity' because it is very difficult to give an account of the content of perceived simultaneity (i.e., is it propositional, epistemic or non-epistemic?). Other issues, such as what are the objects of perceived simultaneity and what could the perceptual organ responsible for it be, are also problematic. In contrast, 'judged simultaneity' is neutral with respect to these issues and correctly conveys the notion that these are cognitive processes in which stimuli are *taken to be simultaneous* by the sensory-motor system, depending on different circumstances. Obviously this 'judgments' happen at the subpersonal level and do not require consciousness, beliefs or inferences of any kind. They are the result of subpersonal procedures that produce an outcome: e.g., perceptual stimuli *a*, *b* and *c* are simultaneous.

determine the amount of time that separates non-simultaneous stimuli. But even if the clocks could be used to determine simultaneity, it would be extremely inefficient for the senses to depend upon the clocks to determine the simultaneity or non-simultaneity of stimuli for the following reason.

Determining the simultaneity or non-simultaneity of radically different sensorial stimuli presents computational challenges that cannot be solved by the clocks. For instance, light travels about a million times faster than sound. Determining the simultaneity or non-simultaneity of visual and auditory information depends on specific characteristics of the *visual* and *auditory* systems and on the distance between the source of information and the receiver. Thus, the most efficient way of determining the simultaneity of sensorial stimuli is that each sense should have its own *threshold* of simultaneity. The evidence confirms not only that this is the case, but also that there are processes that compensate for differences in simultaneity judgments from different senses concerning the same stimuli sources. Thus, the first cognitive step for calculating the duration of intervals or periods is to determine simultaneities, which can then be *correlated* with segments of intervals or phases of periods.

This section is structured as follows. I first review the psychological evidence on sense-specific simultaneity windows. Second, I discuss evidence suggesting the existence of a cross-modal simultaneity window. Third, I explain the relevance of the cross-modal simultaneity window by highlighting its relationship with the clocks. Finally, I conclude by defining the most important properties of the cross-modal window and characterize it as the *sensorial specious present*, which is the first component of the model that I defend in this chapter.

4.2.1. Sense-specific simultaneity windows

As mentioned, the optimal solution to determine the simultaneity or non-simultaneity of stimuli is that each sense-modality should have its own window of simultaneity because of the different characteristics of the media that it is designed to register. In this subsection I present experiments which confirm that indeed each sensory modality has its own window of simultaneity. For instance, the auditory window of simultaneity can be identified by the so-called 'click-fusion' experiment, in which two tones or clicks that are separated by an interval of 2 ms are experienced as a single tone or click. As Ernst Pöppel explains,

> In the case of these chronological differentials, one hears always only one tone, even when an objectively measurable differential, for instance of two thousandths of a second, exists between the two stimuli. The objective chronological difference is in other words insufficient to produce the experience of two separately heard tones. What is separated by two thousandths of a second, what is objectively non-simultaneous, appears subjectively as *one* event, that is to say: In the case of these two acoustical stimuli, we find ourselves inside a single "window of simultaneity." (Pöppel, 1988, 12)

A very interesting aspect of simultaneity windows is that the threshold for registering stimuli as simultaneous varies across individuals. In the case of the auditory simultaneity window it can vary from 2 to 5 ms and it also depends on properties of the stimuli, such as loudness. There is also an age/value correlation: the older the person, the higher the value of the simultaneity window. (Pöppel, 1988, 12) This means that for some people, stimuli can be separated by 5 ms intervals and still be registered as only one stimulus. Once one crosses the threshold (2-5 ms), the stimuli are correctly registered as two distinct sounds.

Thus, the same stimuli, say two sounds with the same pitch, separated by an interval of 4 ms may be judged as simultaneous by one person and as non-simultaneous by another person. The reason why these differences do not cause inter-subjective chaos is that at such small scales, variations in judged simultaneity are negligible. Nonetheless, such differences are undeniable and surprising because two *distinct* sounds appear to be, within the simultaneity window, a *single* sound. Equally surprising is the fact that different sense modalities have substantially *longer* simultaneity windows. Pöppel says,

> If one stimulates the skin with stimuli of short duration, the window of simultaneity is enlarged to about ten thousandths of a second [...] If a similar experiment is carried in the visual modality, sight, we obtain yet another result. In the neighborhood of twenty to thirty thousands of a second have to elapse before two visual impressions appear as nonsimultaneous. Below this temporal boundary everything is simultaneous. Although we like to characterize ourselves as visual animals, our visual system, compared to hearing or touch, is very slow. (Pöppel, 1988, 16)

Pöppel suggests that the lack of experiments on simultaneity windows in the other two senses, taste and smell, may be explained by the technical difficulties for measuring such windows (1988, 16). Experiments on simultaneity windows have confirmed the bizarre fact that the same temporal interval between stimuli can produce experiences of the stimuli as simultaneous or non-simultaneous, depending on the sense modality.

The substantial differences in the duration of simultaneity windows (vision has a simultaneity window *ten times larger* than audition) generate a very significant problem. Many auditory and visual stimuli come from the same source and we need to calibrate the spatio-temporal location of the source and parse the stimuli into simultaneous and non-simultaneous in order to be able to act successfully with the environment. But with the discrepancies between simultaneity windows just mentioned, how are the differently parsed stimuli integrated into a *single sensorial window*, where stimuli from *all the senses* are judged as simultaneously present? Answering this question is the main purpose of the next subsection.

4.2.2. The multi-sensory integration window

The evidence on simultaneity windows reveals that there are substantial differences in their duration, which creates the problem of explaining how is it possible to perform sensory-motor tasks that require cross-modal integration of stimuli into a single multi-sensory percept in virtue of which stimuli from different senses are judged to be simultaneous. As J. V. Stone, et al. (2001) explain in the following paragraph, multi-sensory simultaneity is one of the most fundamental requirements for motor coordination, and there are two possible explanations for how multi-sensory simultaneity may be computed by the brain:

> When executing time-critical tasks, such as playing table tennis, knowing precisely when the ball made contact with the table is important for fast and accurate motor coordination. However, even if the perception of audio-visual simultaneity is not veridical, it should at least be stable for a given observer. Such stability may permit the motor system to be temporally calibrated with respect to the perceived timing of auditory and visual events. These considerations suggest that the perceived timing of visual and auditory events should be highly accurate, or, at least, highly stable for a given observer. (Stone, et al., 2001, 31)

Stone and his collaborators tested these two hypotheses, focusing on the audio-visual integration of stimuli. The hypothesis that the judged simultaneity of stimuli depends on a highly accurate mechanism predicts that there will be little differences in judged simultaneity across individuals. On the other hand, if this hypothesis is false, then there should be a high degree of stability in the duration of the integration window where audio-visual stimuli are judged as simultaneous for each individual, but there should be *variance* across individuals.

Stone, et al. corroborated the second hypothesis. Through a series of experiments that dissociate reaction time tasks (RT) from the so-called ‘point of subjective simultaneity’ (PSS), they obtained the following results. First, the PSS values, which reflect the most likely threshold at which an observer will judge audio-visual stimuli as simultaneous, are *observer specific*.[78] Actually, each observer's PSS value is significantly different from other observers and from the estimated population mean. (See Stone, et al, 2001) This finding shows that there is variation across individuals with respect to aspects of the *multi-sensory simultaneity window*, such as the PSS value. But the PSS value is stable over time for each observer.

The PSS value depends on *spatial* information. For instance, suppose that the PSS is 50 ms, which means that if the onset of the light stimulus came 50 ms before the onset of the sound stimulus, then the sound and light stimuli onsets were judged as simultaneous.[79] This specific PSS of 50 ms depends on the *location* of the observer relative to the source of the stimuli. More specifically, the PSS depends on a *horizon* of simultaneity where the distance of the source of stimuli from the observer, given the radically different speeds of light and sound, is critical for the specification of the numeric value of the PSS. Anatomical features of the sense organs, in this case audition and vision, also play an important role. It turns out that, once one takes into account all these issues, the horizon of simultaneity for light and sound is about 10 meters from the subject.[80]

But what happens when the subject is not exactly at 10 m from the source of stimuli? How does the brain compensate for differences in synchrony, due to the subject's location or other causes of asynchrony, and determine that the stimuli occurred

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[78] More precisely, the point of subjective simultaneity (PSS) is the *stimulus onset asynchrony* at which an observer is *most likely to judge the onset* of a light and a sound as simultaneous.

[79] The Stone, et al. experiment is based on stimulus onset asynchronies that range from –250 ms (sound before light) to +250 ms (light before sound). This 250 ms window is very relevant, as the research that I am about to discuss reveals.

[80] See Callender, C. (2008a) and references therein.

simultaneously? As Craig Callender (2008a) says, although there will be a point at which the horizon of simultaneity is far enough from the subject to hinder judged simultaneity, the sensory-motor system's mechanism for determining the simultaneity of cross-modal stimuli is very tolerant to asynchronous information. Callender explains,

> At some point the brain does not weld the two aspects of the event into a simultaneous whole. The phenomenon of thunder and lightening is perhaps the most conspicuous such case. We hear the sounds later than seeing the light. And if the event is up close, we can react quicker to an auditory source than to a visual one; so up close there are cases where the brain—at least for quick reactions—is not waiting for the visual processing to catch up. Still, the brain is surprisingly tolerant of asynchronous information. There are no noticeable discrepancies between the image of the lips moving and the sound "Now!" at any typical communication distance. (Callender, 2008a, 14)

Callender is referring to an experiment by Dixon and Spitz (1980), which shows that the sound of the word 'now' could be produced as much as 250 ms *after* a person moved her lips (saying 'now'), without the subjects noticing the discrepancy. It is remarkable that the multi-sensory window of integration, in this case limited to audio-visual stimuli, is as large as 250 ms. Although PSS values, which are significantly shorter than the window of 250 ms (because they are the threshold at which a subject will *most likely* judge auditory and visual stimuli as simultaneous) vary from subject to subject, the window for multi-sensory information seems to be around 250 ms. Indeed, the temporal window used by Stone, et al. to identify the PSS values in their study is 250 ms.

A wide multi-sensory integration window of 250 ms (a window that is about a *hundred times larger* than the 2 ms window of simultaneity for auditory stimuli) explains the surprising tolerance of the brain to asynchronous information, described by Callender. Furthermore, other experiments show that there is an active process of *adjustment* and *recalibration* that the brain must perform for integration to happen. Some of the most relevant experiments concerning this issue include those on temporal ventriloquism (e.g., Welch, et al., 1986; Spence and Squire, 2003), motor-sensory recalibration concerning the effects of the subject's intentions (e.g., Eagleman and Holcombe, 2002; Stetson, et al., 2006), cross-sensory recalibration (e.g., Fujisaki, et al., 2004) and distance-based recalibration (e.g., King, 2005).

It is plausible to hypothesize that there is a wide simultaneity window, of about 250 ms, for multi-sensory integration. Although the experiments I have mentioned in this subsection concern exclusively audio-visual stimuli, it is reasonable to postulate that a similar window would be required for the brain to recalibrate multi-sensory stimuli, in order to compensate for asynchronies.[81]

Experiments on the multi-sensory integration window are ongoing. It is a fascinating area of research that is revealing the level of complexity underlying the most basic acts of perception. But there are two fundamental problems that the multi-sensory integration window generates. One concerns the relationship between the clocks and the integration window: is there such a relationship and if so what is its nature? The other problem is the nature of the relationship between the integration window and the smaller windows. These are the issues that I address in the next subsection.

[81] I will soon characterize the mechanism responsible for integration and recalibration within the 250 ms window in more detail, and I will call it the 'cross-modal integration processor.'

4.2.3. The multi-sensory integration window and the clocks

There is another temporal threshold that is highly relevant to understand the relationship between the integration window and the clocks, particularly the stopwatch.[82] I will call this threshold, following Pöppel, the *order* threshold, because it allows subjects to determine which of two non-simultaneous stimuli came first. Below this threshold, subjects can *distinguish* the stimuli, but they are unable to determine *which came first*. In the case of auditory stimuli, which has the smallest simultaneity window, experiments have shown that there is an interval of about 25 to 35 ms in which subjects can distinguish two sounds, but are unable to determine which sound came first. Pöppel describes the results of these experiments as follows:

> A person is in a position to give accurate information only when the chronological separation between the two tones lies in the neighborhood of 30 to 40 thousandths of a second. Although two distinct tones can be heard, a period ten times as long as the approximately four thousands of a second has to elapse before certainty can exist as to which was the first tone and which the second. (Pöppel, 1988, 19)

A very important characteristic of the order threshold is that it is *not* sense specific. This is a perplexing feature of the order threshold because one would think that perceiving the order of sensorial stimuli is something that happens at the lowest level of information processing. Certainly, one would expect that by distinguishing two stimuli as two distinct sounds, the auditory system would *immediately* register which sound came first. However, experiments have shown that the discrimination of stimuli is a necessary, but not sufficient condition for chronological order perception. Why is the chronological order of cross-modal stimuli determined after a *fixed* threshold for all modalities if the

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[82] I say 'particularly the stopwatch' because the stopwatch depends on sensorial stimuli for its activation. But since the window I am about to discuss determines the order of

sense specific windows are *substantially different*? Indeed, it seems very odd to think that the order of sense specific stimuli is determined according to a sense *independent* threshold. But this is exactly what researchers have found. Pöppel explains,

> When the experiment is carried out with tactile or optical stimuli, a marked differential from the window of simultaneity is found in these sensory systems as well. To be able to say that something came first or second requires interestingly enough in each case the same time interval for the three sensory systems […] viz., approximately 30 to 40 thousands of a second, whereas the span of simultaneity is in each case totally different, as we had discovered. (Pöppel, 1988, 19)

Where does this order threshold come from? Notice that in the case of vision, the 20 to 30 ms simultaneity window and the order threshold determine an almost *immediate* discrimination of stimuli *and* their chronological order because there can be at most 20 ms between the discrimination of stimuli as non-simultaneous and the specification of their chronological order. However, the fact that there is a fixed 30 to 40 ms threshold for cross-modal stimuli suggests that there is a *common mechanism* that *compensates* for the differences in durations of the sense specific simultaneity windows and *integrates* stimuli in terms of chronological order across the modalities. Now the question is what are the characteristics of this mechanism? Specifically, is it a clock or a non-temporal mechanism?

There are two hypotheses that have been discussed in the literature, both of which postulate a specific type of relationship between the clocks and the integration window. The first hypothesis postulates that a *clock* is the mechanism responsible for the temporal integration of sensorial stimuli in an ordered sequence. The other hypothesis postulates that there is a non-temporal sensory mechanism that integrates cross-sensory information

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sensorial stimuli, it is also relevant to determine the phase information of the circadian clock. See chapters 2 and 3 for a detailed discussion on how the clocks work.

into ordered sequences that can *then* be used for clock-dependent action coordination. I proceed to explain these hypotheses and argue in favor of the second hypothesis.[83]

As I explained in chapter 2, interval timing is the capacity to estimate durations in the seconds to minutes range. If the stopwatch can discriminate durations at the seconds range, could it also have the capacity to discriminate durations at the milliseconds range? According to the first hypothesis, the order threshold could be explained as the minimum amount of time required for information to be encoded in the memory component of the stopwatch. This explanation has the advantage of being parsimonious, because it avoids postulating a non-temporal cross-modal mechanism for chronological order that outputs information into the clock. The order threshold is fixed and cross-modal because it is a property of the stopwatch's memory component.

Although this is a plausible explanation of the fixed value of the order threshold, evidence favors the second hypothesis. Karmarkar and Buonomano (2007) developed a neural network model for timing at the milliseconds to seconds range that encodes time-dependent information by identifying spatial patterns of neural activation, independently of any clock-related information. Ivry and Schlerf (2008) describe the experimental evidence in support of this model as follows:

> Secondary tasks or pharmacological manipulations affect judgments of 1 s intervals while having little or no effect on intervals of around 100 ms. Secondary tasks that affect judgments of 1 s have little effect on intervals of 100 ms. Temporal acuity normalized to mean duration is relatively constant for intervals between 200 ms to 2 s but becomes considerably poorer for intervals shorter than this range. (Ivry and Schlerf, 2008, 275)

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[83] Notice that the issue is not how the simultaneity of stimuli is determined. Both of these hypotheses *assume* that there are simultaneity windows that determine judged simultaneity. The question is what is the mechanism responsible for determining the *chronological order* of stimuli.

These results suggest a significant discontinuity between the millisecond and the second's range, evident at and over 100 ms, which is well above the order threshold. Additionally, the architecture of the sensory-motor system seems to require a non-temporal mechanism, as the second hypothesis postulates because sensorial information is also relevant for determining the phases of the circadian clock. Given the differences between periodic and interval timing, it is more efficient for the sensory-motor system to have a non-temporal mechanism that outputs sensorial information to the clocks than to integrate such information through the stopwatch.

Moreover, the general properties of interval clocks (particularly the scale/resolution tradeoff), which apply to the stopwatch, make it an unlikely candidate to register durations at such a short scale. As Ivry and Schlerf say: "It is unlikely that a single mechanism could operate at these different time scales. A pacemaker used to judge an interval of 40 s is unlikely to have the resolution to judge a 100 ms interval." (2008, 275) For these reasons, the second hypothesis should be accepted as the correct explanation of the threshold for chronological order, which occurs *within* the range of the multi-sensory integration window, i.e., about 250 ms.

To conclude, this cross-modal mechanism is not designed to register or represent time beyond the milliseconds range and it integrates sensorial information into *ordered* sequences of stimuli previously integrated by sense-specific simultaneity windows. The clocks then use the sensorial information integrated by this mechanism. Although this integration mechanism has temporal *constraints*, as evidenced by the order threshold, it is not a clock. Thus, the order threshold seems to be a property of the integration window, and not of the stopwatch. In the next subsection, I address the issue of whether the multi-sensory integration window could be the so-called *specious present*.

4.2.4. The sensorial specious present

In this subsection, I will argue that the multi-sensory integration window is *one type* of specious present, which I will call the *sensorial specious present*, or SSP. The multi-sensory integration window is the SSP for cross-modal stimuli and each simultaneity window can be considered as a SSP for its specific stimuli. However, given the importance of the cross-modal window for sensory-motor representation, I will refer to the multi-sensory integration window as the SSPI. The SSPI is a crucial component of the model of the present that I propose in section 4.5 of this chapter. For the purposes of my analysis of the SSP in this subsection, by SSP, I mean the *relevant window for judged simultaneity*, *which could be sense specific or cross-modal* (the SSPI). The characteristics of the SSPs and the SSPI are not exactly those that philosophers have discussed in the literature on the specious present.

As Robin Le Poidevin (2004b) explains, since its introduction to the philosophical literature by William James, the characterization of the specious present has focused on its *duration*. Thus, proposals for characterizing the specious present have explained it in terms of the duration of short-term memory or the duration of a unit or event (a sentence or a musical phrase). These characterizations also emphasize that the specious present has a structure that links the past with the future smoothly, which is the basis for the perception of motion and change. In contrast, the most important characteristic of any SSP is that stimuli are *judged* as simultaneous, regardless of specific durations or the capacity to link the past with the future. Le Poidevin's (2004b) characterization of the specious present (unlike other philosophical accounts of the specious present) comports with this property of the SSPs:

> The *doctrine of the specious present* holds that the group of events we experience at any one time as present contains successive events spanning an interval. The experienced present is 'specious' in that, unlike the objective present, it is an interval and not a durationless instant. […] What matters, as far as the doctrine is concerned, is not when an event occurred, but when information from that event reached our sense organs. Thus, light beams from two events may reach the retina at slightly different times, and yet the two events be perceived as simultaneous. (Le Poidevin, 2004b)

As mentioned, SSPs have different durations, but they will always involve an *interval*, as the doctrine of the specious present stipulates. Considerations about distance, speeds of media (i.e., light or sound) are all relevant to the duration of the SSPs. However, exactly *when* these stimuli reach the sense organs is difficult to determine. What really matters is that we judge the stimuli within the SSPs to be simultaneous. As Le Poidevin (2004b) says: "In these cases, we see things as simultaneous when they are not simultaneously presented to our sensory apparatus, and that is the basis of the true doctrine of the specious present."

It is very important to emphasize that although cross-modal simultaneity can occur within the postulated duration of the SSPI (i.e., the 250 ms), 250 ms is the *maximum* duration of the SSPI. The duration of SSPs, as mentioned, will vary for each modality. After only 30 to 40 ms (the order threshold) one can judge not only *non-simultaneity,* but also the *chronological order of stimuli*. However, this only holds for stimuli occurring within a *specific modality*. Although the threshold is *cross-modal*, i.e., it has the same value for all modalities, the stimuli needs to be occurring *within the same modality* to be registered as chronologically ordered after 30 to 40 ms. The cross-modal information processing of the SSPI has different temporal constraints.

The SSPI has a longer window of simultaneity, around 250 ms: it is more *tolerant* to asynchronies between cross-modal stimuli, as was discussed in subsection 4.2.2. What matters for any case of SSP is, as Le Poidevin says, that stimuli be judged as simultaneous, not that they occur within a single and specific interval of time. So the traditional philosophical question, “how long is the specious present” is not meaningful without further clarification. One has to be much more specific in characterizing the specious present. The SSPI happens to be the longest window for judged simultaneity, but this does not mean that non-simultaneity cannot be registered within much shorter durations, such as the 2 to 5 ms window of the auditory modality.

However, it is confusing to say on the one hand that the 30 to 40 ms order threshold is a property of the multi-sensory integration mechanism, and on the other hand that the duration of the SSPI can be as long as 250 ms. But as was explained in 4.2.2, speed, location of the observer and distance must be compensated for the integration of multi-sensory stimuli, which makes such integration much more difficult than the within modality order-specification. The integration mechanism determines the order threshold, but the order threshold does not determine the SSPI’s duration because the order threshold affects only stimuli within the *same* modality.

One can illustrate this as follows. Suppose there are three different creatures with the same simultaneity windows that humans have. One of them (*A)* depends exclusively on auditory information. Another one (*V*) depends exclusively on visual information and the remaining one (*AV*) uses both auditory and visual information. The SSP for *A* will *always* be 2 to 5 ms, for *V* it will *always* be 20 to 30 ms and for *AV* it will depend on whether the stimuli are sense-specific or audio-visual. In other words, the SSP for *AV* is whichever window of simultaneity is *relevant* for a specific set of stimuli. In the case of humans, it is normally the SSPI.[84]

A crucial question that needs to be addressed in order to understand the importance of the SSPI is: what happens to the asynchronous information from sense-specific windows when the SSPI integrates it? The evidence shows that asynchronous sense-specific stimuli are judged as simultaneous within a *single* window of simultaneity for cross-modal stimuli. This means that the SSPI imposes the relation of simultaneity among asynchronous information a *second time*.

For creatures like humans, whose sensory-motor system depends on cross-modal information, the SSPI is the most relevant window of simultaneity, and the "first" simultaneities of the sense-specific SSPs are, as it were, *erased* by the SSPI and can only be detected through clever experiments that probe only *one* modality. These "first" simultaneities unify asynchronous stimuli into a simultaneous whole, but unlike the SSPI, this process of unification is not one of *cognitive integration*.[85] This explains why the asynchronies determined by the order threshold are ignored by the mechanism responsible for determining the SSPI (which I will call the *cross-modal integration processor* or CMIP). I shall now spell out in more detail this integration process by postulating a principle that I will call 'unification':

> **Unification:** Once the asynchronies of previous windows are integrated and re-calibrated into a new window (the SSPI) these asynchronies disappear and the stimuli

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[84] An interesting question is whether creatures *A* and *V* would have an order threshold. The evidence suggest that creatures that do not need to temporally integrate cross modal stimuli would not need such a threshold because the threshold is a property of the integration mechanism.

amalgamate into a single moment, the present, where cross-modal stimuli are related by simultaneity.

Finally, I shall mention that Le Poidevin's account of the specious present has the advantage of avoiding two issues that have been problematic.[86] The first one comes from James's statement that the specious present's duration can range from a few seconds to probably more than a minute. (1890, 603) By constraining the specious present to the interval(s) of time in which stimuli are judged as simultaneous, Le Poidevin effectively restricts this controversial interval of time to the specific and experimentally tested values below 250 ms. The second issue also originates from James's account of the specious present, i.e., that the specious present has earlier and later parts of which we are presently aware. This has been considered puzzling because it is impossible to judge stimuli as simultaneous and as not simultaneous at once. But philosophers have argued that this blatant contradiction seems indispensable to make sense of the perception of change and motion, which makes the specious present paradoxical.

However, this alleged paradoxical nature of James's specious present is not pertinent to any discussion concerning the SSP for the following reason. Stimuli registered within any SSP are indisputably related by *simultaneity*, which is a *symmetric, transitive and reflexive* relation. Judging something as chronologically order requires an *asymmetric* relation, e.g., 'before than' or 'after than'. Clearly, stimuli are either related by

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[85] For the importance of cognitive integration as a criterion for representation see chapter 3, specifically 3.4.5.

[86] Recently, Le Poidevin (2007) has characterized what I call the SSP as the "experienced" present, and has contrasted it with James's notion of the specious present, which includes the perception of what has just passed and the anticipation of what is about to come, like in the perception of motion. Since I find Le Poidevin's distinction

simultaneity or by an order relation, but they cannot be related by both. By stating that stimuli registered within the specious present are always registered as simultaneous, Le Poidevin avoids the difficulties just mentioned.[87]

I have talked about the SSPs, their range and properties, which vary depending on the modality. There is also a SSP (the SSPI) that governs the integration of cross-modal stimuli. But what *kind* of mechanism is responsible for integrating stimuli into simultaneities. I mentioned that the mechanism responsible for determining the SSPI has to be a non-temporal mechanism. But this negative characterization is vague: many mechanisms are 'non-temporal' and it would be better to have a positive characterization of this mechanism. In the next section, I argue that however it is instantiated and however many sub-components it may have, the cross-modal integration processor (CMIP) is a *meta-semantic mechanism* and also that the SSPI is the *temporal mental demonstrative*, the mental equivalent of the indexical 'now'.

4.3. Meta-semantic mechanisms and the temporal indexical

The sensory-motor system needs to coordinate action-oriented representations with features of the environment. It also needs to individuate and select packets of information that are relevant for action, perception and motor control by eliminating noise and unnecessary information. In the case of the circadian clock and the stopwatch, their analog outputs need to be anchored to the present moment in order to provide accurate

(and his discussion of the relevant literature) confusing, I will only refer to his (2004b) assessment of the specious present, which is much clearer.

[87] What about the perception of change and motion? Perceiving change and motion depends on mechanisms that differ from those involved in the integration of stimuli in the SSPs, which only concerns the *simultaneity* of stimuli. Thus, giving a full account of motion and change perception goes beyond the present study. However, perceiving

temporal information to the sensory-motor system. The present moment or SSPI (i.e., the amount of time in which stimuli are judged as presently simultaneous by the sensory-motor system) is determined by the CMIP. The relationship between the CMIP and the clocks is that the CMIP individuates, *via* the SSPI, the packets of information that the clocks use to anchor their analog representations.

More specifically, the circadian clock needs to anchor its analog representations of the cycle in which the earth rotates on its own axis to the present moment. This is crucial for the use of circadian clock information in navigation because computing the solar ephemeris function depends fundamentally on determining which phase of the clock corresponds to the present moment. Phase resetting also depends on such anchoring because it basically consists in changing the phase that corresponds to the present. Likewise, the stopwatch needs to anchor a specific moment of its analog representation of intervals to the present in order to determine elapsed time from the moment of activation.

One can easily exemplify this kind of "anchoring" of the outputs of the clocks by comparing the clocks with a speedometer, which was a useful way to illustrate the analog nature of clock-representations (the main topic of chapter 3). Speed is continuously represented by the surface in which the pointer of the speedometer moves. The pointer moves continuously and smoothly through the surface, always marking a specific speed. Analogously to a speedometer, the clocks need a pointer that *selects* a particular phase of the circadian cycle or a specific moment of an interval registered by the stopwatch. This pointer is the present moment. Like an arrow in a map, it informs the sensory-motor system what phase or moment is occurring now.

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change and motion depends on the SSPI, the clocks and spatial representation

But when I say that the outputs of the clocks need to be anchored, what does this exactly mean? The metaphor of "anchoring" mental representations to features of the environment needs to be spelled out, particularly with respect to something like the present moment, i.e., to what exactly are the outputs of the clocks anchored? Presumably to the SSPI, but what kind of representation (if it is a representation) is the SSPI, and how does it anchor the outputs of the clocks?

The SSPI and the sense-specific SSPs are representations in the sense that they are sensorial *constructs*. This is why they vary depending on the modality and from person to person. But if the SSPI is a representation, how could it *misrepresent*: it is not clear that it maps onto anything in particular. The present (i.e., the SSPI) simply *picks out* or *points to* a time (a phase of the circadian cycle or a moment of an interval). Thus, a crucial problem that needs to be solved in order to explain what the anchor metaphor means is to provide a full characterization of the SSPI. Notice that the SSPI has an important property that only representations have: it allows for cognitive integration with other sensory-motor representations (like the outputs of the clocks). Actually, it itself is the result of cognitive integration.

I shall now focus on the SSPI because, as mentioned, it is the relevant SSP for the sensory-motor *system.* Thus, in what follows, for the sake of simplicity in presentation, *every instance of the term 'SSP' refers to the SSPI.* Because of *Unification*, the SSP can anchor the representations of the clocks to a *cross-modal present*. Now, as I just mentioned, the problem is to give a characterization of the SSP that explains in more detail the anchor metaphor.

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mechanisms. Therefore, what I say in this chapter is relevant for such an account.

Fortunately, the issue of how to characterize the anchor metaphor has been addressed in the philosophical literature. I will argue that the SSP is what Joseph Levine (MS) calls a *mental demonstrative*: a representation that affords direct access to what is demonstrated. It is a particular kind of mental demonstrative, one that Levine calls *token-demonstrative*, because it does not pick out a type that refers to a token. Rather, it picks out directly a token without the mediation of a type. In the case of the SSP, it picks out directly a token moment in time during which stimuli are registered as simultaneous.

Expressions that demonstrate or refer directly have been shown to have specific properties that are relevant to the topic at hand. Hans Reichenbach (1947) called expressions that play this directly referential role 'token-reflexive.' The reflexivity of these expressions consists in the fact that it is the utterance *itself* e.g., 'I', 'here' or 'now', that directly designates a person, a location or a moment in time. These expressions are important and unique because they change reference as a function of context and also because they are not translatable to non-indexical expressions (hence their name, *pure* or *essential* indexicals). (See Perry, J., 1979)[88]

But the point I want to make with respect to the SSP is psychological, rather than linguistic. The temporal anchor, or the mental equivalent of the indexical 'now', must depend on a causal, data driven mechanism that directly refers to moments in time. Just like in any language there are expressions, like the pure indexical 'now', that refer directly to a token moment in time, there must be *representations* that behave in exactly the same way. Among these representations there must be a *temporal* mental

[88] Kaplan, D. (1989a) distinguishes pure indexicals e.g., 'I', 'here' and 'now' from demonstratives e.g., 'this' or 'she', because although both vary their reference as a

demonstrative, i.e., the mental equivalent of 'now.' I will argue that the mechanism responsible for generating the temporal mental demonstrative (the SSP) is the CMIP. Explaining this claim in more detail is the purpose of the remainder of this section, which is organized as follows. 4.3.1 discusses the importance of meta-semantic mechanisms and 4.3.2. focuses on the temporal meta-semantic mechanism.

4.3.1. The need for meta-semantic mechanisms

As mentioned, the temporal mental demonstrative is crucial to anchor the representations of the clocks. In general, mental demonstratives, particularly those equivalent to the so-called 'pure indexicals', play a fundamental role in theories of mental content because they anchor or "center" a subject at a place and time. One way of studying mental demonstratives is through language, by analyzing the way in which indexical expressions, and linguistic utterances in general, refer. Levine, following Kaplan (1989b), distinguishes two kinds of question that need to be addressed in order to study the content of mental demonstratives (and mental content in general) through language: the semantic and the meta-semantic questions.

Levine says that the semantic question "concerns the specification of the content of a representation; what are its truth conditions? how does it behave in modal contexts?" The meta-semantic question "concerns the conditions by virtue of which the representation has the content it has; what makes it the case that this representation has this content?" (MS, 6) Levine exemplifies this distinction with Saul Kripke's (1980) causal theory of names:

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function of context, indexicals only require context to determine their reference. Demonstratives require context *and* ostention or demonstration.

> On a Kripkean account of proper names, the semantic question is answered by the direct reference theory. The name "Socrates" functions to refer to the guy, Socrates, and the referent is its semantic value. However, there is a longer account, involving dubbing ceremonies and historical transmissions, which answers the meta-semantic question; namely, how it is that our use of "Socrates" now refers to the ancient Greek philosopher. (Levine, MS, 6)

Philosophers of language have written extensively on the semantic question concerning pure indexicals and other demonstrative terms. However, the meta-semantic issue on which I will focus in this section (i.e., how the temporal indexical *refers* and acquires its content) demands a causal-psychological explanation. In the specific case of the clocks, a temporal mental demonstrative (the equivalent of the indexical 'now') is required to ground their periodic and interval information. A *causal* explanation of the *temporal mental demonstrative* (TMD) must answer the question: how does the brain create a causal link with the environment, such that a temporal referential relation is established?

The TMD can be defined as the mental equivalent of the indexical 'now', which anchors the periodic and interval information of the clocks to the present. The SSP is the best candidate to fulfill the role of TMD because it explains how the nervous system, through the causal process of calibration performed by the CMIP, *points*, or *picks out*, specific moments in time by integrating them into cross-modal windows of simultaneity. An adequate meta-semantic account of the TMD must explain how the SSP performs the task of referring to moments in time and also describe the meta-semantic function of the causal mechanism (the CMIP) in more detail. I address these issues in the next subsection.

4.3.2. The temporal direct-meta-semantic mechanism

As mentioned, the CMIP creates the causal link that determines the TMD by integrating a simultaneity window (the SSP). The TMD *is* the SSP, but the term 'TMD' refers exclusively to the *referential* and *anchoring* function, rather than the *stimuli integration* function, of the SSP. It is, as it were, the indexical *alias* of the SSP. I shall now describe in more detail how the TMD and the CMIP fit into a broader theoretical framework concerning mental representation. Levine distinguishes two kinds of meta-semantic mechanisms. *Intentionally mediated meta-semantic mechanisms*, which depend essentially on the content of another representation to secure reference and *direct meta-semantic mechanisms*, which do not depend on other representations to secure reference. (Levine, MS, 9)

Direct meta-semantic mechanisms are important to explain how the mind connects with the world and also why certain perceptual representations seem to be *en rapport* (or in direct acquaintance) with features of the environment. The mechanisms involved in these cases seem to refer directly, via a causal link with the world. I submit that the CMIP is a direct meta-semantic mechanism. One can illustrate this by contrasting the CMIP with the clocks. Assume that phases and segments of intervals are labels for moments in time in a representation space. Focusing on the circadian clock, suppose that an animal phase-locks its circadian clock to the moment in which food is available, say 3:30 a.m.

In this case, the circadian clock would work as a temporal intentionally mediated meta-semantic mechanism because it would refer to an individual moment in time, i.e., 3:30 a.m. via another representation concerning food availability. Certainly, a phase of the clock *by itself*, say the one that corresponds to 270°, does not refer directly to a moment. Rather, it refers indirectly, in relation to other phases and based on the isomorphism that exist between the cycle of the circadian clock and the period of the rotation of the earth on its own axis. In other words, 270° labels a phase that is relevant for behavior in a way that resembles a description. This *highlights the need for a direct meta-semantic mechanism* that links this mental description with a specific moment in time, which is another way of saying that the representations of the clocks need to be anchored by the mental equivalent of the indexical 'now.'

The reason why the TMD requires the postulation of a direct meta-semantic mechanism is deeply related to the characteristics of pure indexicals. The pure indexical 'now' is not translatable to non-indexical expressions. No name, label or description of a moment can capture the content of 'now.' If I call a moment 'phase 358°' and describe it as 'the moment at which the meeting takes place', I am not providing any information as to what *particular moment* in time this name and description refer to. Suppose you want to know which particular moment 'phase 358°' refers to, and I give you more coordinates and descriptions (e.g., 'phase 358°' correlates with 12:00 pm, the time called 'noon'). Although you have more information about the reference of 358° you still do not know what specific moment it refers to, until you are able to "point at it" somehow and determine that *now* is noon, and thus, I am now at 'phase 358°'.

You may have temporal representations, like 'phase 358°', or 'yesterday at 9 pm.' but these representations cannot be correlated with token moments in time without the existence of a causal link between the sensor-motor system and the environment, which the CMIP provides. Thus, the CMIP is not only responsible for determining simultaneity relations. It also plays the much more important role of being the direct meta-semantic mechanism for temporal representations, particularly clock representations. The TMD is the most fundamental type of temporal indexical, upon which the linguistic temporal indexical is based.[89]

To conclude, I shall present a graphic representation of the first component of the two-phase model of the present that I outline in section 4.5 of this chapter. I will call this component, the 'sensorial specious present (SSP)'. Its main characteristics, which I have explained in the previous sections, can be captured by the following figure ('DMM' stands for 'direct meta-semantic mechanism' and it is an acronym used by Levine):

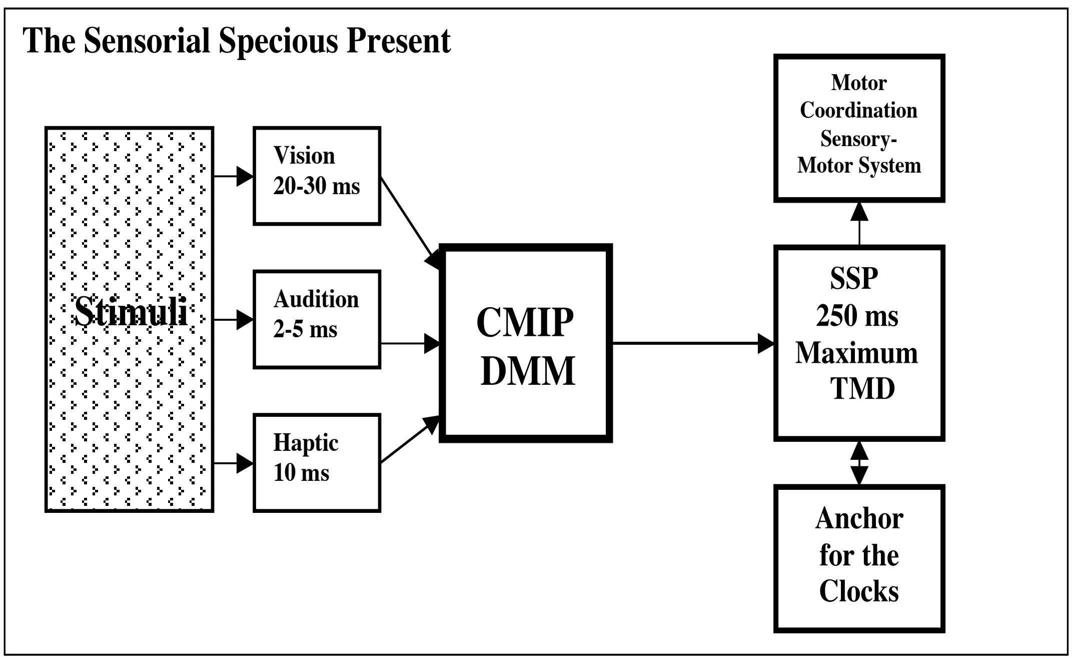

Figure 1. The SSP: First component of the two-phase model

[89] Linguistically, 'now' varies its duration depending on context and *pragmatics*, e.g., 'Now is 2008', 'Now is time to go to school', etc. The CMIP determines the most fundamental, *causally determined* and unmediated indexical reference for moments in time: the TMD. Notice that all the pragmatic cases involve *intentionally mediated meta-semantic mechanisms*.

This model of the specious present omits the sense-modalities of taste and smell because of the lack of experimental evidence. The arrows indicate casual order, and explain the informational processes that lead to the determination of the SSP-TMD. The double arrow between the clocks and the TMD indicates the specific anchoring function of the TMD. The word 'maximum' indicates that the value of 250 ms is the temporal limit of the SSP: a value that will vary and can only be approximated, but will always be below 250 ms. I will henceforth refer to this model simply as the 'SSP'.

4.4. The phenomenal present

Can the SSP explain how we *experience* the present? An affirmative answer to this question would be: by determining the simultaneity of cross-modal stimuli, the SSP anchors sensory-motor representations in the present, providing the sensory-motor system with a *sense of presence*. The SSP explains how we experience the present because it is responsible for *grounding* experiences in the present. A negative answer would be: what is meant by the term 'experience' is the *conscious experience of the present*. The SSP is at best a crude approximation to such experience because it lacks the necessary structure to explain crucial *phenomenological* characteristics of the consciously experienced present. Some of these characteristics are: a) an "openness" and "retentiveness" that is not captured by the simultaneity relation imposed by the SSP: a property that I will call 'OR' and b) a unity and continuity that cannot be accounted for by the mere *sum of discretely instantiated SSPs*. This unity and continuity are frequently associated with the term 'stream of consciousness.'[90]

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[90] These two properties of the experienced present are central to William James's (1890) original characterization of the specious present. James famously said that the present is not a knife-edge but a saddleback.

Both answers seem equally compelling and I will argue they are both correct because there are two kinds of specious present. I will call the period of time in which one is *consciously aware* of a thought or perceptual experience the *phenomenal specious present* (PSP). The purpose of this section is to describe the PSP, offer evidence concerning its duration and structure and explain why the PSP indeed has properties a) and b). However, before proceeding, I shall explain properties a) and b) in more detail.

With respect to property OR, it was Edmund Husserl who first developed a systematic account of the phenomenal present in terms of ‘protention’, ‘primal presentation’ and ‘retention’. Since there is considerable scholarly debate about what exactly Husserl meant by these terms, and particularly about how they structure what he called ‘inner time-consciousness’, I will remain neutral with respect to hermeneutical issues regarding Husserl’s work. Instead, I will use two examples to convey the main idea behind OR.

The first example concerns music. Suppose you are listening to a song—or even better, put on some music and *listen* to one of your favorite songs. As the notes pass by, you are aware not only of a momentary note at a time (certainly not the time determined by the SSP: at most 250 ms). While you listen to the song, you are not listening to a set of *momentary notes*. Your experience of the song simply cannot be captured by a sum of auditory SSPs because you seem to be listening to *the song*, with all its harmony and unity, not to any particular note or set of notes.

Moreover, a crucial part of your experience of listening to the song is that you *expect* certain notes to come. Also, the experienced harmony of the song you are listening consists in your *retaining* the notes that just passed, unifying them smoothly with those that are occurring now and also with those that you are immediately expecting. Disharmony, or at least extreme surprise, would ensue if you suddenly listened to a completely unexpected set of notes or if you could not retain the sound of the notes that just passed.[91]

So the question is, if the SSP cannot explain your experience of listening to the music because of its essential characteristics (i.e., it has an extremely short duration and it is structured in terms of simultaneity and not chronological order*, which is an asymmetric relation* that is required for the retention and expectation of notes) then what *can* explain your experience of listening to the music? And for *how long* can you experience the stream of sounds as *presently experienced* before they turn into memories or non-perceptual expectations?

Another illustration of OR concerns emotions and feelings. The following example involves the so-called ‘fringe feelings,’ which are experiences with no specific content. Barry Dainton (2004) offers many examples of fringe feelings, but perhaps the most relevant one for the present discussion is:

> Think of what it is like to carry out a task with the reassuring feeling that everything is proceeding as it should—or with the feeling that it isn’t. […] There is a feeling or intuition with a quite specific character, a feeling whose significance is entirely unambiguous, but one that does not posses a qualitative character of a sensory kind. (Dainton, 2004, 371)

Other relevant cases of fringe feelings are: “being in a state of readiness, opening or straining one’s senses, being prepared for the unexpected, being determined or resolute”. (Dainton, 2004, 372) As Dainton says, although these feelings are easily overlooked, they

[91] This gets a lot more interesting and complicated if you are singing and dancing at the same time. You are not experiencing your dancing as a *sum of momentary body*

are actually "significant ingredients in our overall consciousness." (2004, 371) OR can be illustrated through other examples, but these two cases (listening to music and fringe feelings) suffice to convey the main idea behind this notion. I shall now briefly illustrate the unity and continuity of the PSP, or the 'stream of consciousness' (SC) with another quote from Dainton. The PSP is allegedly the manifestation of the structure of consciousness, which is described in very metaphorical terms, as a continuous "flow," or "stream," that unifies the whole of our conscious experience:

> Our ordinary streams of consciousness may usually be composed of continuous (gap-free) stretches of experience, but their unity is more far-reaching. Yes, we experience continuously, but continuity is also something we experience, all the time. Think of what it is like to view the passing countryside from the window of a moving train: trees, roads, buildings—you watch them all sliding by. This smooth continuous movement is something you actually *see*, not merely infer. […] Our ordinary experience is not merely continuous, continuity is a ubiquitous presence in our experience. (Dainton, 2004, 373)

It is important to notice that the continuity of the stream of consciousness is not dictated by a succession of events. It is more like, as Dan Zahavi (2005) says, a *temporal field* of conscious awareness. The question is, how to make sense of this metaphorical way of characterizing the properties of the PSP? Just as with the SSP's 'anchor' metaphor, more needs to be said about the alleged properties of the PSP. The remainder of this section provides a more detailed description of the essential characteristics of the PSP, while paying close attention to the experimental evidence.[92] Section 4.4.1 discusses

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movements. You simply experience it as *dancing*, and more specifically as dancing *to the music: your favorite song*; likewise with singing.

[92] It is important to mention that although the PSP has implications for central issues in phenomenology and the study of consciousness, I will not defend a particular thesis on *what* is consciousness or phenomenal content (or what are the necessary and sufficient conditions for a mental state to be a conscious one) because it would exceed the scope of my analysis.

experimental evidence concerning the duration of the PSP and 4.4.2 focuses on the relation imposed by the PSP, which differs significantly from simultaneity.

4.4.1. The phenomenal specious present

As mentioned, there are two *empirical* issues concerning the PSP. The first one is what mechanism, or set of mechanisms, can explain the properties of the PSP and the second one is *how long* is the PSP? Addressing these issues would significantly improve our current understanding of the PSP, which depends mostly on phenomenological accounts. In this section, I will address the second question and leave the first one to section 5, where I present my own proposal of the PSP.

As in the case of the SSP, evidence suggests that the PSP is also *specious*, in the sense that it has duration, i.e., it occurs during a specific interval of time rather than at a durationless instant. There are two important findings concerning the duration of the PSP. One concerns the minimum temporal threshold required for content to become conscious and the other concerns the maximum threshold of the PSP.

A very important finding concerning the PSP, specifically regarding its minimum threshold, comes from the research of Benjamin Libet. Although highly criticized, Libet's findings on conscious awareness have been considered to be valuable experimental evidence on the temporal dynamics of conscious awareness, with significant implications for the scientific study of consciousness.[93] Libet (2004) summarizes this finding as follows:

> If you tap your finger on a table, you experience the event as occurring in "real time". That is, you subjectively feel the touch occurring at the same time that your finger makes contact with the table. But our experimental evidence strongly supports a surprising finding that is directly counter to our own intuition and feelings: The brain

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[93] See Dennett, D. (1991); Wegner, D. M. (2002) and (2003) and Penrose, R. (1996).

> needs a relatively long period of appropriate activations, up to about half a second, to elicit awareness of the event! Your conscious experience or awareness of your finger touching the table thus appears only after the brain activations have become adequate to produce awareness. (Libet, 2004, 33)

What interests me about Libet's finding is the period of time that, according to him, it takes the brain to produce awareness: up to about *twice the maximum for the SSP* (500 ms). But before discussing the importance of Libet's finding for the duration of the PSP, I shall address two issues that need to be clarified in order to understand the nature and scope of this finding.

The first issue concerns the reliability of our conscious experiences as evidence of psychological processes. Libet's result is not the only psychological experiment that challenges our intuitive subjective experience (in this case of our awareness of events as occurring in real time). Psychological findings, from change and inattentional blindness to research in motor coordination, have proved that our conscious access to psychological processes is very misleading. Thus, Libet's finding confirms what many other psychological experiments have revealed about the shortcomings of conscious awareness, and should not be considered controversial merely because it challenges intuition.

The second issue is a more substantial one and it can be succinctly captured by the question: how should we interpret the experiments on the SSP, were subjects *register* the non-simultaneity of stimuli at durations much shorter than *250 ms*? If subjects are able to *distinguish* the non-simultaneity of very short events, which presumably require their *being aware* of such non-simultaneity, what could Libet be talking about when he says that it takes up to 500 ms for *their brain* to elicit awareness of an event? Researchers have asked this question to Libet, and his response is:

> We are talking here about *actual awareness* of a signal, which must be clearly distinguished from the *detection* of a signal. For example, human and nonhuman beings can discriminate between two different frequencies of tactile vibration, even though the intervals between the two pulses in each vibration frequency are only a few milliseconds […] The ability to detect differences in millisecond intervals is undeniable, but when is one *aware* of that detection? Becoming consciously aware of the difference is what requires the relatively long time. In other words, detection leading to some response can occur unconsciously, without any awareness of the signal. (Libet, 2004, 33-34)

Although we are indeed *unaware* of a lot of sensory-motor information that plays a major role in our daily life, Libet's response is unsatisfactory because it relies on the ambiguity of the term 'awareness' without fully clarifying what *he* means by awareness.[94] However, Libet's lack of clarity does mean he lacks experimental evidence. His findings *do* suggest a cerebral delay for awareness, which as Libet highlights, is not at odds with other psychological findings.

For instance, as Libet says: "cognitive, imaginative, and decision-making processes all can proceed unconsciously, often more creatively than in conscious functions." (2004, 100) Evidence on what Pylyshyn calls 'vision-without-awareness' shows that crucial sensory-motor information that is plainly in view and can become consciously available upon attending to it, is processed by the brain even though the subjects are unable to report their being aware of such information.[95] The findings on 'vision-without-awareness' include: "change blindness, inattentional blindness, visuomotor control

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[94] Of course, this is a Pandora's box. Libet's contrast between *distinguishing* and *being aware of* something seem to rely partly on the reportability and phenomenal content of the experiences of which we are consciously aware. But these issues are very problematic. For instance, Ned Block (1995) classifies consciousness into "access" and "phenomenal". As mentioned, I will not delve into the controversial topic of consciousness because it exceeds the goals of the present discussion and I will remain neutral with respect to any theory about what consciousness *is*.

[95] See also Velmans, M. (1991).

without conscious awareness, blindsight, visual agnosia and disorders of visual-motor coordination." (Pylyshyn, 2007, 144)

Suppose we accept Libet's interpretation and agree that conscious awareness occurs around 500 ms after the event that triggered the relevant neural activation. Is there any other experimental evidence that would explain other properties of the PSP, such as its *upper threshold*? Fortunately there is. But before commenting on this research, I shall state more precisely Libet's proposal for a cerebral delay of "up to 500 ms". In the context of a discussion on the implications of his findings with respect to the issue of free will, Libet suggests that in the case of a subject's awareness of her own will or intention to act, the lower threshold of the PSP, which is up to 500 ms, may be shorter: 400 ms. Even in the famous skin stimulation experiment, Libet used a 300 ms stimulus and he frequently characterized the cerebral delay as an interval of 300-500 ms (2004). This is the reason why some authors say that Libet's results show that there is a delay between readiness potential and awareness of *at least* 300 ms.[96]

I do not want to endorse Libet's controversial claims about free will. What I want to emphasize is that his findings could be interpreted in a similar fashion to the findings concerning the SSP: they demonstrate the existence of a temporal threshold that seems relevant to conscious awareness, which is consistent with other psychological findings.[97]

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[96] See for instance Pylyshyn, Z. W., (2007).

[97] For example, the distinction between unconscious and conscious information processing can also be explained in terms of action-outcome (A-O) associations based on declarative memory for conscious information, and stimulus-response (S-R) associations based on procedural memory for unconscious information. It is known that after training animals, A-O associations can become S-R associations (See Cheng, et al.). This is actually a quite familiar phenomenon, like when one learns how to drive: a lot of attention and conscious awareness is necessary at the beginning, but unnecessary once one *learns* how to drive. The threshold found by Libet could explain the A-O/S-R divide

Just like the 30-40 ms threshold determines the lower boundary for chronological order, the 300-500 ms threshold determines the lower temporal boundary of the PSP. Now the question is, what is the upper temporal boundary and how can we explain properties OR and SC which, as mentioned, cannot be captured by the relation of simultaneity or a sequence of simultaneities?

Research on ambiguous or multistable images, such as the Necker cube, provides answers to these questions. Multistable images are *perceptually* interpreted in mutually incompatible ways. For instance, the Necker cube can be perceived as a cube with a lower *or* an upper front but never as *both*, which would be actually impossible. These mutually incompatible interpretations "flip" or alternate spontaneously. Gestalt phenomena, which have always been defined as irreducible to the *summation* of discrete configurations (something that will be relevant for property SC), are also ambiguous, such as the "duck-rabbit" image, and these interpretations also alternate spontaneously in the same way as the Necker cube.

Ever since the work of Wilhem Wundt, it has been demonstrated that it takes from 2.5 to 3 seconds to integrate sequential stimuli into *experiential* units (for instance a sequence of sounds into a unified rhythm). In the case of ambiguous images, we can attend only at one of the incompatible interpretations, i.e., we can attend at the rabbit or at the duck, but not at both. What is interesting is that these interpretations spontaneously alternate at the *same rate*: every 2.5 to 3 seconds. Pöppel explains,

> Ambiguous figures allow us an interesting insight into the dynamics of the process of consciousness. A content of consciousness can apparently persist up to circa three seconds. If nothing new is presented requiring other events in the environment to be

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by appealing to the decrease in time involved in the transition from A-O to S-R associations.

> acknowledged, the alternative perspective thrust itself automatically into the foreground of consciousness. If still nothing new occurs—if we are again, that is, not "diverted"—then after a few seconds the first perspective returns to consciousness, and so on. After a few seconds, then, the capacity for integration is exhausted. (Pöppel, 1988, 60)

The PSP can be characterized as the *window of integration for conscious experiences*. If the main role of the SSP is to anchor the outputs of the clocks and sensory-motor representations in general, then the main role of the PSP is to "melt" or amalgamate into an experiential whole the information specified by discrete instantiations of the SSP with other relevant information. In the case of ambiguous images, the PSP integrates sequential information into a single *coherent interpretation*: either a duck or a rabbit. The same happens when there is no perceptual ambiguity: the PSP integrates the information from a set of instantiations of the SSP into a phenomenal unit. And as Gestalt psychologists say, the phenomenal unit cannot be explained as the mere sum of discrete representational items, i.e., the *image does not change*; yet it can be interpreted either as a duck or a rabbit, but never as both. Pöppel calls this "the capacity for integrating chronologically sequential events into a present gestalt." (2004, 63)

Thus, the evidence suggests that the PSP has an upper threshold of 3 seconds and a lower threshold of 300-500 ms. The principle of unification governing PSP information processing can be characterized as follows:[98]

P-Unification: Once a set of perceptual simultaneities determined by consecutive anchorings of the SSP is integrated into a window of phenomenally unified

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[98] It is important to mention that the evidence concerning the upper temporal bound of the PSP and the unifying character of the PSP is much more robust that the one regarding the lower limit (Libet's experiments) and involves a variety of different experiments. See for instance Pöppel, E. (2004) and references therein.

experiences by the PSP, the discreteness of these successive simultaneities disappear and the stimuli amalgamate into a single experience, the phenomenal present.

There is one key ingredient missing in this principle: what is the relation that determines *P-Unification*? In the case of SSP-Unification, it was simultaneity. What relation could be responsible for *P-Unification*? In the next subsection, I address this question and elaborate on how *P-Unification* explains OR and SC.

4.4.2. The relation responsible for ***P-Unification***

Dainton (2000, 2004) has offered an enlightening analysis of the relation responsible for phenomenal unification, which he calls 'co-consciousness'. In such a short presentation, I cannot do justice to all the careful argumentation that Dainton offers to support his account of the stream of consciousness. However, I will comment on some aspects of his account that are relevant to the topic at hand. Before assessing Dainton's notion of 'co-consciousness', I shall briefly describe how he understands its relationship to the specious present. Dainton (2004) says,

> I will use the (less than optimal) term 'specious present' to refer to those brief phases of our streams of consciousness during which we are directly aware of change and persistence. Since a specious present has some (apparent) temporal depth, it has (seemingly) earlier and later parts; and since the transition between these parts is directly experienced, the parts are *phenomenally connected*—they are co-conscious, but diachronically rather than synchronically. (Dainton, 2004, 374)

Two issues are highly relevant about what Dainton is proposing. The first concerns the *duration* of the specious present. Dainton says that 'specious present' refers to brief phases of our stream of consciousness that can be connected synchronically and diachronically. How long are these brief phases? He quotes Pöppel's evidence concerning the order threshold and says that the specious present's lower threshold is 30 ms. (2004, 374) This duration is somewhat compatible with my characterization of the SSP, but it is incompatible with my proposal for the PSP, which is what is at stake here. However, since Dainton is not making the distinction between SSP and PSP, the issue of duration does not present a major problem for his proposal.

A more significant problem arises from what Dainton says about the upper bound of the phenomenal present. He defends an overlap model for the connection between specious presents, according to which "a *stream* of consciousness does not consist of a succession of self-contained chunks or pulses of experience, laid end to end like a row of bricks." Rather, Dainton continues, "We must recognize the phenomenal connections *between* them." (2004, 378) He realizes that in order for the overlap model to work, there must be an upper bound that temporally (rather than *phenomenally*) delineates each specious present. Dainton mentions the 3-second upper limit (which is the upper limit that I propose for the PSP) and writes,

> The figure of three seconds […] is based on people's ability to discern distinctive, memorable, or pleasing patterns in their experience, *temporal gestalts*: think of how the notes in a musical phrase, or the words in a line of spoken poetry hang together, or seemingly form natural units. However, given that these patterns extend quite some way through time, there is no guarantee that the beginning and end of a given pattern fall within the scope of immediate experience. For my own part, I would tentatively estimate the duration of my typical specious present to be half a second or less. (Dainton, 2000, 171)

There are three problems with Dainton's characterization of the upper bound of the PSP. First, why would Dainton opt for *his* personal estimation of the specious present, rather than for the *experimental evidence* that he is referring to? Second, the experimental evidence has nothing to do with "patterns." Rather, such evidence has revealed, as Pöppel says, the temporal dynamics of *awareness in general*. Think about the experiment with ambiguous images. What is the "pattern" in this experiment? The image *does not change at all*, so there is no pattern in the stimulus. One of the perceptual interpretations comes to the foreground and the other one recedes, and they keep flipping every 3 seconds even though the image is the same. Third, which is the most substantial problem, why should the upper bound be 500 ms or *less*? This value is what Libet says is the *minimum* threshold required for sensory-motor information to become conscious.

These are significant difficulties with Dainton's proposal that have a negative impact on his account of co-consciousness. Dainton explicitly says that there is diachronic and synchronic co-consciousness. This means that, by definition, co-consciousness cannot be *simultaneity* because it is a contradiction to say that simultaneity can be diachronic. But then what *is* co-consciousness? Notice that the question concerning duration could also be asked with respect to phenomenal connectivity as follows: for *how long* could a set of experiences be phenomenally connected by co-consciousness? Simplicity demands that the answer to this question should be: however long the PSP *is*. This is the proposal that I favor, but Dainton's overlap model seems to suggest that the length of the specious present is always shorter that the extension of any unified experience connected by co-consciousness.

Dainton characterizes co-consciousness as a primitive relation, which is a feature of experience analogous to color or sound, unexplainable and non-analyzable. (2000, 236) He also says that it is *transitive* at "any given moment shorter than the specious present" but co-consciousness over time is *not transitive*. (2000, 172) For instance, three total experiences (which I am about to define) X, Y and Z "can be such that X is co-conscious with Y, Y with Z, but X is not co-conscious with Z." (2000, 172) An important contribution of Dainton's work is his notion of 'total experience', which includes not only perceptual and other sensory-motor information, but thoughts, feelings and emotions. He claims that co-consciousness unifies all these experiences as follows: "Co-consciousness is a relation, its terms are experiences, and so far as individual total experiences are concerned, it is reflexive, symmetrical and transitive." (Dainton, 2000, 219)

Dainton's characterization of co-consciousness has several advantages because it explains the higher degree of integration of the PSP, which includes *any* type of experience. It also elucidates how unity and a degree of continuity are achieved by the symmetrical and reflexive linking of all experiences at a "moment in time." But, as mentioned, determining how long this moment *is* presents a significant difficulty for Dainton. However, let us assume for the sake of argument that Dainton has a solution to this problem. There is another fundamental problem that needs to be solved, i.e., how to make sense of the *non-transitivity* of diachronic co-consciousness? As Dainton acknowledges, the non-transitivity of co-consciousness in the synchronic case is *incomprehensible*, but it is *inevitable* in the diachronic case:

> To the extent that our streams of consciousness require non-transitive co-consciousness, it is tempting to suppose that non-transitivity and temporality are essentially linked, and this further strengthens the case for thinking that synchronic co-consciousness cannot fail to be transitive. (Dainton, 2000, 182)

Dainton is right in saying that synchronic co-consciousness cannot fail to be transitive, but the explanation of this aspect of synchronic co-consciousness has nothing to do with co-consciousness, but with *simultaneity*. Obviously, *anything* judged as happening at the same time, regardless of it having the property of being conscious or not, will be related according to a symmetric, reflexive and *transitive* relation, i.e., simultaneity.

Any sensory-motor information within the SSP is unified by simultaneity, as I explained previously. But the anchoring determined by the SSP occurs unconsciously, and thus, representations within the SSP will not be co-conscious with anything. [99] I submit that a scientifically informed account of the PSP should take into consideration the findings on simultaneity windows. What Dainton calls synchronic and diachronic co-consciousness are not two versions of the same relation. Rather, they are two radically different relations. In the case of the SSP, the unifying relation is simultaneity. I shall now proceed to characterize the relation that unifies the experiences or representations of the PSP, which will also explain how instantiations of the PSP relate to each other.[100]

The representations of the PSP cannot be related by simultaneity because the maximum threshold of 250 ms for simultaneity is below the postulated minimum threshold for the PSP. However, this does not mean that phenomenologically it may *seem* as though such contents are simultaneously co-occurring. But phenomenologists actually challenge the view that simultaneity is the relation that best captures the phenomenal present because of properties OR and SC. In the literature on the philosophy of perception, particularly on phenomenal content, there is a debate that speaks directly to the issue of how to best characterize this non-simultaneous "togetherness" of perceptual presence, which I proceed to explain.

I will call the relation responsible for PSP unification, *phenomenal binding* (PB). PB behaves as the perceptual relation 'looking the same as', which is at the center of the

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[99] I realize that this is very counterintuitive. However, as I explained in 4.1 lack of awareness in sensory-motor processes has been demonstrated experimentally in a vast number of studies.

debate on perceptual indiscriminability. According to Neslon Goodman (1951), this relation is not transitive.[101] The more general 'looks like' is indisputably symmetric, reflexive and not transitive. Although 'looking the same as' is stronger than 'looks like', it is not *identity*. Thus, it seems safe to characterize 'looking the same as' as not transitive. So what are the consequences of characterizing PB in terms of the relation 'looking the same as' as construed by Goodman?

First, the unity and continuity that Dainton rightly wants to account for is preserved. An experience of anger and an experience of pain co-occurring within a PSP (but even in between or across PSPs) will be co-conscious or phenomenally bound to other experiences, such as visual experiences, as long as the subject is *aware* of them. But a token experience within the PSP is not *guaranteed* to be phenomenally bound to *every* other experience *within or across* PSPs. To better understand this, it is useful to picture phenomenal binding as a *continuum* that comes in degrees, similarly to the phenomenal continua that can be compared in terms of 'looking the same as.'

If we take color, for instance a particular shade of red, such a color will look the same as any other shade that is very close to it in the continuum. At some point, thought, the indistinguishability will weaken and the relation 'looks the same as' will no longer be

[100] I say that the PSP relates experiences or representations because I want to remain neutral with respect to the representationalist v. non-representationalist approaches to phenomenal content.

[101] Delia Graff (2001) has challenged this view and argued that 'looking the same as' is transitive. I will not delve into this issue here because her arguments do not jeopardize what I am saying: my ultimate goal is not (like hers) to compare phenomenal properties. Rather, I am trying to make sense of properties OR and SC by analogizing PB with Goodman's assessment of 'looking the same as' regardless of whether he is right about indiscriminability.

transitive with respect to those shades of red that are "far away" in the continuum.[102] So what is the analogy between 'looking the same as' and PB? That PB relates experiences in a continuum in much the same way. Instead of strong resemblance between phenomena, however, PB unifies experiences in terms of *conscious salience*, which depends on our limited capacity for attention.

Suppose that you are angry at a speech you are watching on T.V. PB unifies your experiences of anger, maybe combined with frustration, with visual and auditory experiences of a specific person and a specific voice. And, maybe that is it. You might be computing other sensory-motor information (actually a huge amount of it) and a significant amount of this information might actually become an experience. But at the *moment* in which you are angry listening and watching the speech, demarcated by the PSP, this information is simply not part of what you are experiencing, i.e., it is not bound by PB.

To continue with this illustration, suppose that while you are angry listening at the speech, you are eating something. You swallow what you are eating and then after say, half a second, you focus your attention on what you just swallowed and then ask yourself, what am I eating? While you were angry, you were not noticing the flavor of what you were eating, but this does not mean that you were not processing this information. Once you focus your attention on the taste of what you were eating, you realize it is an apple, which you confirm visually by looking at the apple, instead of staring at the T. V.

Now think about the way in which PB unifies these experiences into a phenomenal unity. There are no "gaps" between your experience of anger and your experience of

[102] This is what generates the so-called 'phenomenal sorites.'

tasting the apple. These were the two most salient experiences and they could have happened *within* a PSP or during a *transition between* PSPs. But this actually *does not matter*. By suddenly shifting your attention from being angry to tasting the apple, PB has unified these experiences smoothly. But is your auditory experience of listening to the speech *while you focus on tasting the apple* bound by PB to your experience of looking at the apple. It does not seem so, for what would that mean?

It would mean that your experience of listening to the speech is phenomenally unified with your experience of looking at the apple, but this does not capture the fact that you have *shifted* your focus of attention and that the sound of the speech, unlike the experience of anger associated with it, has now receded and lost conscious salience. Continuing with the analogy, your auditory experience is "further away" in the continuum bound by PB. But, if this is so, then PB is not transitive, because if it were, these experiences *should* be unified by PB.

I submit that this characterization of PB is the only way to explain the phenomenal 'flip-flop' involved in ambiguous images. Suppose you are looking at one of these images. You are, in ways that can be demonstrated experimentally, computing information about the image's interpretations. But PB only *consolidates* one of these interpretations and then, once the PSP is over, smoothly suggests the alternative one. And this is only because you are not distracted, because if you were, as in the case of asking yourself what you are eating, then your new taste experience will continuously and smoothly follow your experience of looking at the image. Thus, the PSP is not a sort of knife that chops experiences into segments. It is just a threshold that demarcates how long can a *single experience be experienced as phenomenally present.*

Therefore, being related by PB does not *entail* transitivity or intransitivity, i.e., PB is a non-transitive relation. PB does entail symmetry and reflexivity. By connecting smoothly transitions between experiences and by amalgamating salient experiences, PB explains both OR and SC. It explains, for instance, how we can have a fringe feeling of expectation alone, and how we can combine this feeling with the expectation of *seeing* someone. In order to be more precise, one can characterize PB according to the following principles:

PB symmetry: If an experience X is phenomenally bound to another experience Y, then Y is also phenomenally bound to X.

PB reflexivity: Any experience X is phenomenally bound to itself.

PB non-transitivity: If an experience X is phenomenally bound to another experience Y, and Y is phenomenally bound to another experience Z, then it follows neither that X is phenomenally bound to Z nor that X is not phenomenally bound to Z.

A consequence of PB's non-transitivity is that in order to decide whether X and Z are phenomenally bound, we need to determine their degree of salience, which depends on the limited attentional capacity of a subject and her *focus of attention*. It is wrong to think that we experience a vastly rich amount of sensations at a time, specifically, within the PSP. Perceptual presence is never the result of an all-encompassing synesthetic *melting pot*. On the contrary, it is the result of a highly selective process.

This actually explains why phenomenal presence, based on the PSP, has the properties OR and SC. Each experience bound by PB can be immediately linked to whatever grabs our conscious awareness and each experience bound by PB can be connected to whatever experience a subject *decides to attend to*, regardless of whether the experience is sensorial or not. And finally, another important consequence of the properties of PB is that *within any PSP, there is always a set of experiences that are phenomenally bound*.

My characterization of the PSP and PB has the unsettling consequence that we are never consciously aware of sensory-motor simultaneities, and this is exactly why the PSP is truly a *specious* present. Although we *seem* to be *directly acquainted with the present*, we are never acquainted with a discrete 'now' were *simultaneity* relations among stimuli can be isolated. It is true that we are in direct rapport with perceptually calibrated simultaneities through the SSP, and even the SSP is specious in the sense that it has duration, although an extremely short one. But we are unaware of the information produced by the "direct rapport" between the sensory-motor system and the times picked out by the SSP, which comports with the "brute-causal" nature of the link *required* for the CMIP to be a direct meta-semantic mechanism. Taking into account the characteristics of PB we can re-define P-Unification as follows:

> **P-Unification:** Once a set of perceptual simultaneities determined by consecutive anchorings of the SSP is integrated into a window of phenomenally unified experiences by the PSP, the discreteness of these successive simultaneities disappear and the stimuli amalgamate into a single experience, the phenomenal present, where experiences are related by phenomenal binding.

It is difficult to explain the relationship between the SSP and the PSP. I will offer some insights in the next section, in which I present my own model of the present.

4.5. The two-phase model of the present

In this section, I outline a *two-phase model of the present*. I will briefly describe the two main components of the two-phase model of the present, or TPMP and then address the issue of the relationship between the SSP and PSP. The TPMP has two components. The SSP is the temporal mental demonstrative of the sensory-motor system and its main function is to anchor the representations of the clocks. The stimuli integrated by the SSP are related by *simultaneity*. The PSP is the other component of TPMP. Its main function is to unify experiences, which are related by *phenomenal binding*. Since this entire chapter has been devoted to defining these components, I shall proceed to describe their relationship.

What happens to the set of chronologically ordered simultaneities within a PSP when, by means of attention, a subset of them are integrated in terms of PB? Based on *P-Unification*, the answer is: the discreteness of the simultaneities disappears and they are amalgamated into a unified experience. But by means of which process is this achieved? In the case of the SSP, it is a *cognitive integration* process that recalibrates cross-modal asynchronies and relates them in terms of simultaneity. But the PSP is radically different. Although it is a cognitive integration process, it does not concern recalibration and it relates experiences in terms of PB. Given the complexity of this issue, there is no clear and principled way of defining the relationship between the SSP and the PSP. But one way to capture the transition from the ordered simultaneities of a sequence of SSPs to the experiences related by PB is to describe it as a *phase transition*.

By 'phase transition' I mean an abrupt change in the structure of a system, like the abrupt change that happens in the structure of the molecules of water in the transition from liquid to solid. The structure of the “now snapshots” of the SSP change *abruptly* when they become bound by PB. More specifically, the discreteness of the instantiations of the SPP disappears. The purpose of this analogy is simply to convey why modeling the transition between the SSP and the PSP, required to fully capture the two-phase model, is not a matter of graphs or boxes. However, figure 2 aims to give an idea of how the first phase of the TPMP looks like:

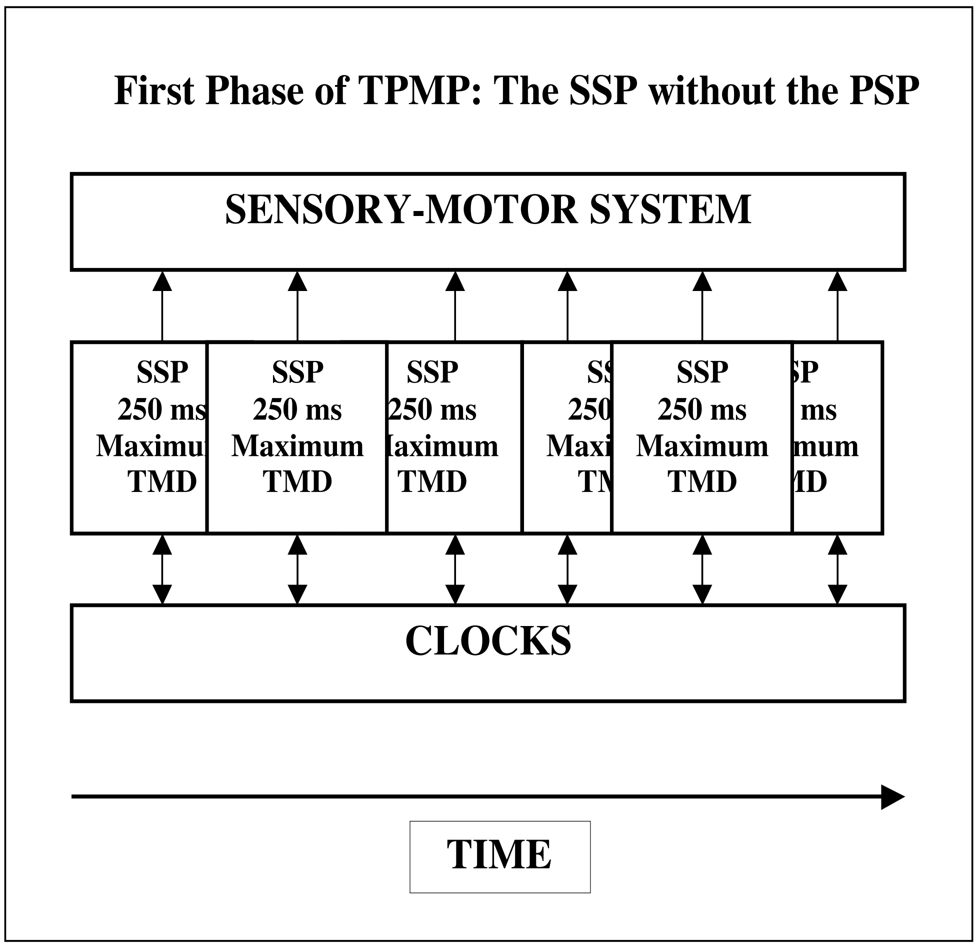

Figure 2. The SSP without the PSP

Figure 2 illustrates how SSPs can be no longer than 250 ms but they can be shorter and there is significant overlap between them. The SSP is constantly anchoring the clock-representations and outputting information to the rest of the sensory-motor system. The overlapping SSPs of figure 2 could exemplify a table tennis competitor. Some determinations of the simultaneity of cross-sensory stimuli take more than others, but none exceeds 250 ms.

It is important to mention that the TPMP model does not strictly depend on the values I have been relying upon to describe the temporal boundaries of the SSP and the PSP. If science finds other values that differ slightly from the values I am using, the TPMP would still be the best available model of the present because what matters is that there will be such values demarcating the temporal distinction between the unconscious influx of sensory-motor information determined by the SSP and the experiences that the PSP frames. And with respect to the visualization of the PSP, try to imagine a foam "dissolving" figure 2 and selecting a subset of the information: that would illustrate the transition between the SSP and the PSP.

Finally, what is the relationship between the *clocks* and the PSP? The clocks may interface with the PSP in two ways. The first, proposed by Pöppel (1988, 48) is by imposing a serial chronological order to the stimuli anchored by the SSP, that is then related by PB. The PSP, through PB, uses this information to generate coherent and highly organized experiences or temporal gestalts. The second, which has not been suggested in the philosophical or psychological literature, is that the clocks might be responsible for generating the sense of "flow" of time that we experience as the continuity of the phenomenal present. But these are two highly speculative theses.

The TPMP has interesting implications for how we are acquainted with the present, which I describe in the next chapter. To conclude, the most important advantages of this model are: a) it is based on scientific evidence; b) it offers a detailed characterization of its components in terms of cognitive function; c) it provides a novel way of addressing philosophical issues concerning the duration of the present (depending on the type of information, a maximum of 250 ms for the SSP and of 3 s for the PSP) and d) it spells out clearly how the SSP relates to the other main temporal mechanisms of the sensory-motor system: the clocks.

Chapter 5

Implications of my Proposals for Debates in the Metaphysics of Time

5.1. Introduction

I mentioned (in chapter 3) that the metric outputs of the clocks determine representation spaces of possibilities that structure and organize the behavior of an animal by guiding it successfully in the environment, helping it decide the best course of action and eliminating disadvantageous alternatives. In the case of the circadian clock, its outputs provide a *phase-based* representation space of possibilities for action that allows the animal to anticipate periodic events and navigate. And in the case of the stopwatch, its outputs provide an *aperiodic interval-based* representation space that allows the animal to accurately anticipate non-periodic events, compare intervals and decide from moment to moment of an elapsed interval which option is the most favorable.

In chapter 4, I explained that there are two types of specious present with different maximum thresholds (depending on the type of information, a maximum of 250 ms for the SSP and of 3 s for the PSP) and provided a *two-phase model of the present* (TPMP). In this chapter, I describe the implications of the TPMP for debates in metaphysics that touch on the issue of our immediate acquaintance with (or epistemic access to) the present.

In section 5.2, I focus on a type of claim which states that our immediate acquaintance with the present should play a role in justifying certain metaphysical views. I articulate an argument that formalizes this claim and justifies choosing a particular theory of time (i.e., the A-theory) over its rival (i.e., the B-theory) based on its representational advantage or intuitive strength. In section 5.3, I discuss two ways of disambiguating the term ‘subjective present’ (which is used in the premises of the argument described in section 5.2) and argue that these two interpretations have implications for debates in the metaphysics of time. Section 5.4 expands on the implications I describe in 5.3, focusing on how a particular interpretation of ‘subjective present’ strengthens the case for the A-theory. Finally, I summarize the main conclusions of my thesis in section 5.5.

But before proceeding, I shall make a few general remarks about the potential impact that findings in cognitive science may have with respect to metaphysics. Cognitive science is particularly relevant for evaluating claims about: a) the way in which the world appears to us and b) the origin of the intuitive power of metaphysical views. The way in which the world appears to us, and the intuitive power of metaphysical theses are commonly employed as sources of evidence that metaphysicians use to support their claims. Addressing topics a) and b) through cognitive science will certainly shed light on how to evaluate the veracity of claims concerning the descriptive accuracy of metaphysically relevant appearances or experiences, and the intuitive power of metaphysical views.

With respect to two fundamental metaphysical issues, i.e., object persistence and the problem of determinism, cognitive science is already suggesting new ways in which metaphysicians could inform their views and re-shape metaphysical debates. In the case of object persistence, Brian Scholl (2007) has suggested that identifying the psychological mechanisms that underlie our intuitions about spatiotemporal continuity, persistence through property change and cohesion may lead to philosophical progress:

> Understanding the origins of our metaphysical intuitions in various psychological mechanisms could help us understand when they are worth revising or forfeiting in

> our philosophical theories, especially if there is reason to think that those psychological mechanisms may yield unreliable results in the particular contexts in which they are being asked to operate. (If, for example, a theory of persistence demands that we give up the intuition that property changes involve true alteration of persisting objects, then we may be comforted to know that the reason we have that intuition in the first place is not because of any intellectual obligations due to other beliefs, but only because in visual experience we represent property changes by altering persisting *representations* of objects.) In general, understanding where metaphysical intuitions come from is one way that psychology might usefully contribute to philosophy, rather than trying to replace it. (Scholl, 2007, 586)

I do not endorse specific claims by Scholl about how psychological findings on object persistence may clarify or revise particular metaphysical views. Rather, I want to illustrate how, similarly to what happened with scientific evidence from the natural sciences, cognitive science is opening new alternatives for metaphysicians to *support, revise or disambiguate* their claims. As Scholl says, with respect to object persistence, cognitive science helps distinguish intuitions that depend directly on how our psychological mechanisms operate from those that depend on other beliefs or theoretical frameworks.

In the case of the problem of determinism, cognitive science provides metaphysicians and philosophers in general with the unprecedented possibility of verifying the veracity of philosophical claims concerning the origin and justification of certain intuitions. In a paper on the compatibility of moral responsibility and determinism, Shaun Nichols and Joshua Knobe (2007) say,

> Although philosophers have constructed increasingly sophisticated arguments about the implications of people's intuitions, there has been remarkably little discussion about *why* people have the intuitions they do. That is to say, relatively little has been said about the specific psychological processes that generate or sustain people's intuitions. And yet, it seems clear that questions about the sources of people's intuitions could have a major impact on debates about the compatibility of responsibility and determinism. There is an obvious sense in which it is important to figure out whether people's intuitions are being produced by a process that is generally reliable or whether they are being distorted by a process that generally leads

people astray. (Nichols and Knobe, 2007, 663-664)

Identifying the psychological sources of intuitions and determining whether a particular cognitive process is reliable are important contributions of cognitive science to metaphysics. But there is another crucial way in which evidence from cognitive science can inform metaphysical debates, which is by clarifying and making more precise the notions and statements that metaphysicians use when they talk about our experiences and intuitions. As a concrete example of this, I will argue that with respect to the metaphysics of time, metaphysicians can benefit from research in cognitive science that may help them disambiguate, clarify and eventually systematize the use of their terminology concerning the 'subjective present' in arguments about time in which they appeal to *our acquaintance* with the present.

Let me elaborate on what I propose to be the contribution of cognitive science to the problem of how to best approach metaphysical issues. Alvin Goldman (2007) has outlined a program that specifies how cognitive science can inform and reshape metaphysical debates. He illustrates this program with concrete examples (such as metaphysical claims about language and color) and applies it to the ontology of events.

As Goldman says, there are at least two types of revision that can happen as a consequence of scientifically informed evaluations of metaphysical claims (2007, 460).[103] First, metaphysicians may find that scientific evidence supports an eliminative thesis, e.g., that color does not exist or that free will is an illusion. Second, metaphysicians may find that scientific evidence supports a particular metaphysical account that is based on *experience* or *commonsense*, or the evidence may support a significantly different

[103] See also Goldman, A. I. (1987 and 1989).

account, without requiring an eliminative thesis.

The proposal for disambiguating the term 'subjective present' that I am about to offer is an instance of this second kind of revision. More specifically, I will argue that cognitive science should inform metaphysical claims that appeal to our experience of temporal becoming, which have played a significant role in some debates about the plausibility of the A-theory. I will focus on the subjective present and its importance in making more precise the notion of 'experience of temporal becoming.'

5.2. The 'present' in the metaphysics of time

The phenomenon of temporal becoming seems to be deeply rooted in *conscious awareness* and our intuitions about time.[104] Events seem to come from the future, then become present and finally become past. We seem to be moving along with the present, as the future approaches and the past recedes. This suggests that events have different ontological status depending on whether or not they instantiate the properties of *being future*, *being present* or *being past*.[105]

Metaphysicians who claim that these are *objective* properties are called A-theorists, or tensers. A-theorists hold different views. Some of them deny the very existence of the future (no-futurists) and others deny the existence of the past and future (presentists). Presentists will recognize objective truths *about* the past. But all A-theorists agree that time cannot be completely described without using tensed language and that the present

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[104] See Baker, L. R. (1979).

[105] There is debate about whether or not these properties are monadic. See Zimmerman, D. (1998) and references therein. In propositional terms, temporal becoming is the thesis that propositions change truth-value. See Prior, A. N. (1959).

is a privileged moment in time.[106] For no-futurists or "growing-block" theorists, the present is the last moment in time; for presentists it is the only moment in which events or objects exist; and for eternalist A-theorists, who accept the existence of all times, the present is unique because it is the moment of time that delineates the past from the future.[107]

The uniqueness of the present moment is also deeply rooted in the phenomenon of temporal becoming. It seems that a good metaphysical theory of time *should* account for the uniqueness of the present, with which we become acquainted through our *experience* of time. But how to make sense of the notion that our immediate acquaintance with the present (call it the 'subjective present') should lead us to believe that there are objective facts about the present? How to account for the apparently fundamental relationship between our epistemic access to the present and the objective property of *being present*? These are difficult questions. For instance, Neil McKinnon (2003) explains why our experience of the present has metaphysical significance as follows:

> What is it that makes the presentist theory of time so compelling? Its appeal is often said to reside in the way that it illuminates the temporal aspect of human experience. Psychologically, there is something special about the present. All of our thoughts, feelings, and actions occur there […] Present awareness is fresh, immediate, lustrous, and sometimes exciting in a way that past awareness never is. Given the psychological uniqueness of the present it is therefore tempting to imbue this specialness with ontological import—to make this psychological centrepoint a centrepoint of our metaphysics. (McKinnon, 2003, 305)

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[106] See Tooley, M. (1997) and McCall, S. (1994) for non-presentist versions of the A-theory that describe the present as a privileged moment in time.

[107] The eternalist version of the A-theory is problematic because it could be a version of the B-theory: a semantic view called 'taking tense seriously'. See Zimmerman (2005), who argues that eternalist versions of the A-theory have the risk of collapsing into such a B-theoretic semantic view (the B-theory denies that *being future*, *being present* or *being past* are objective properties).

The intuitive power of the A-theory, in this case a version of it, is based on how we experience temporal becoming. McKinnon is referring to what is generally accepted to be one of the main strengths of the A-theory, i.e., it is a metaphysical account of time that explains and comports with our experience of temporal becoming. If no other theory of time can account for our experience of temporal becoming then, other things being equal, the A-theory must be preferred.

Before assessing specific aspects of the intuitive basis of the A-theory, I shall try to formalize McKinnon's claim. My goal is to avoid inane characterizations of this type of argument concerning the intuitive strength of the A-theory and to present a clear and empirically adequate version of it. If such a formal characterization is to be successful, then it should account for any metaphysical claim that appeals to experiences in order to favor a metaphysical view or theory, based on its intuitive power. I propose the following argument schema:

The Representational Advantage Argument (RA)[108]

(1) *R* is psychologically fundamental and enjoys a privileged intuitive status.

(2) If *R* is psychologically fundamental and enjoys a privileged intuitive status, then we should believe that there are objective facts about *M*.

Therefore, we should believe that there are objective facts about *M*.[109]

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[108] I am using the term 'representational advantage' in a somewhat analogous way to Roberto Casati's (2003) use of it. In his use of the term a representational advantage is a way in which our cognitive apparatus favors one type of entity over another (a similar notion can be found in Goldman's (1989) distinction between 'natural' and 'contrived' entities from the viewpoint of naïve metaphysics). In the sense I am using it, 'representational advantage' depends on the notion of 'psychological fundamentality', and it could be a feature of a *theory* that is intuitive because it accounts for a psychologically fundamental representation and gives it metaphysical significance.

Of the two premises of RA, it is premise (1) that imposes the most significant constraint on the kinds of experiences or representations that are suitable for having metaphysical significance. By ‘psychologically fundamental’ I mean that the representation or experience must be such that without it cognitive representation in a particular domain would not be possible. More specifically, in the case of the temporal representations I have been focusing on, psychological fundamentality means that these representations are indispensable for the sensory-motor system to *refer* to stimuli and attribute sensorial properties to them, thereby making possible a primitive kind of subject-predicate distinction at the sensorial level.[110] Call this kind of psychological fundamentality ‘strict fundamentality’ or ‘s-fundamentality’.

In the previous chapter I described an instance of s-fundamentality because without the mental temporal demonstrative (the SSP) phases of the circadian clock could not be *referred to* by the sensory-motor system and phase-based information from the clock could not be anchored in the present moment. Sensory-motor distinctions that are crucial for producing representation spaces of possibilities for action, such as ‘phase 215° is 15° from the present phase’ or ‘the current phase is 200°’ could not be made without the SSP. And the same holds for segments of elapsed intervals emulated by the stopwatch. This makes the SSP psychologically fundamental, according to s-fundamentality. To appreciate how restrictive s-fundamentality is, consider that, besides temporal

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[109] *R* stands for a representation or experience and *M* for a feature of the world. RA is an argument schema because it depends on the specification of *R*, i.e., its plausibility depends on the *evidence* for its premises when *R* is specified.

[110] See chapter 1 for a more detailed account of this notion, specifically section 1.2.

representations, only spatial representations would pass the test of being *indispensable* for the sensory-motor system to refer to stimuli, as I explained in chapter 1.

I first defined 'psychologically fundamental' in relation to cognitive domains and then refined this definition by focusing on the sensory-motor system and the notion of s-fundamentality. This is because it is desirable to have more flexible accounts of psychological fundamentality that would take into consideration other representations and experiences that are fundamental within a cognitive domain (e.g., representations of the self in the mind-reading domain, syntactic representations in the linguistic domain, etc). But since metaphysical significance is an intricate issue, it is appropriate that s-fundamentality eliminates most experiences and representations.

For instance, it is plausible to say that if the representation or experience *R* is psychologically fundamental, one must be immediately acquainted with *R*. Perceptual (and more generally *sensorial*) representations are classic examples of such cases. However, although we are immediately acquainted with color and experiences of disgust, these experiences are of no metaphysical significance according to s-fundamentality because experiences of color and disgust are not *indispensable* for the sensory-motor system to refer to stimuli and operate reliably. For example, even if a creature lacked the capacities of seeing color and having experiences of disgust, it could still navigate successfully in its environment and detect stimuli, based on spatiotemporal coordinates. However, without spatiotemporal representation, *no* creature could navigate successfully and register stimuli.

Is RA an adequate argument schema on which metaphysicians can rely to assess the *explanatory power* of metaphysical theories? That will depend on the specific case.

Consider the case of space, which is the only other fundamental magnitude that would pass the s-fundamentality test, i.e., determining referents of the sensory-motor system. We represent space as being three-dimensional and this representation and our experience of space as being three-dimensional, have a privileged intuitive status.

It seems plausible to say that space *itself* is three-dimensional. Otherwise it would seem very difficult to explain why is it that we experience space as three-dimensional, which should lead us to believe that space itself is three dimensional (i.e., premise (2) of RA seems to be satisfied). So it seems, for example, that any theory of space (including *scientific* theories of spacetime), which postulate that space is three-dimensional should be preferred, other things being equal, over other theories that do not (say higher dimensional theories of spacetime). So RA seems to work fine in the case of the other primitive magnitude, i.e., space.

As mentioned, more flexible definitions of psychological fundamentality are possible and the plausibility of RA would certainly decrease as the definitions increase in flexibility. I shall now focus on what is allegedly the basis of the intuitive power of the A-theory, i.e., that it explains the way in which we experience temporal becoming and particularly, that the subjective present is critical to experience temporal becoming or the "flow of time." Substituting *R* with 'subjective present' yields the following argument:

The Representational Advantage of the A-theory Argument (RAA)

(1) The subjective present is psychologically fundamental and enjoys a privileged intuitive status.

(2) If the subjective present is psychologically fundamental and enjoys a privileged intuitive status, then we should believe that there are objective facts about the

present.

Therefore, we should believe that there are objective facts about the present.

RAA concerns the intuitive power of the A-theory because it justifies believing that there are objective facts about the present (a central tenet of the A-theory) based on the psychological fundamentality of the subjective present. More specifically, premise (2) of RAA can be inferred from two premises that depend upon the intuitive strength of the A-theory, as the following argument (which I will call Intuitive Strength, or IS) makes explicit:

Intuitive Strength (IS)

(1) If the subjective present is psychologically fundamental and enjoys a privileged intuitive status, then the A-theory is the most intuitive theory of time.

(2) If the A-theory is the most intuitive theory of time, then we should believe that there are objective facts about the present.

Therefore, if the subjective present is psychologically fundamental and enjoys a privileged intuitive status, then we should believe that there are objective facts about the present. (This is Premise (2) of RAA).

Premise (2) of RAA and IS (and the conclusion of both arguments) concern the epistemological issue of what one *should* believe to be an objective fact. Premise (2) of RAA states that one should believe that there are objective facts about the present on the basis of the psychological fundamentality of the subjective present. Premise (2) of IS states that one should believe that there are objective facts about the present because the A-theory is the most intuitive (or commonsensical) theory of time. But what justifies this epistemological principle? Dean Zimmerman (2008) specifically addresses this issue as follows:

> Epistemologists have learned something from the failure of modern attempts, from Descartes onward, to find absolute certainties and infallible chains of reasoning that take us from these certainties to the rest of the things we think it is reasonable for us to believe. The moral is this: unless we are willing to become extreme skeptics, we must allow that it is reasonable to believe things that seem obviously true, in the absence of special reasons to doubt them; and we must allow this even if the beliefs are admittedly not certainties, and cannot be "proven" in any interesting sense of the word. This conclusion privileges commonsensical beliefs. To be part of commonsense, a thing must seem obvious to almost everyone. So, for almost everyone, it is reasonable to believe it – in the absence of serious objections. It is "innocent until proven guilty. (Zimmerman, 2008, 222)

Zimmerman's appeal to commonsense to defend why it is reasonable to believe things that seem obviously true to everyone is very relevant for assessing the merits of premise (2) of RAA and IS. Indeed, there is no reason to doubt obvious and commonsensical beliefs (like the belief that the present is a privileged moment in time) if there are no serious or conclusive objections against it. Thus, even if it is not a scientific certainty that the present is a privileged moment in time, it seems *obvious* to everyone that it is, and giving up such fundamental and obvious beliefs is unjustified in the absence of serious objections, which is what makes premise (2) of RAA (and IS) true.

What I say in the remainder of this chapter makes RAA (the argument on which I will mainly focus) more precise. I will specify, based on scientific evidence, what is the *cognitive basis* of the widely held belief that there are objective facts about the present. Zimmerman's argument contains another important criterion for defending the plausibility of RAA, which is that scientific evidence must be taken into consideration in order to determine whether or not there are serious objections against the metaphysical significance of the present. This criterion can be formulated as follows:

Scientific Plausibility of the A-theory (SP)

(1) Either there is conclusive evidence against the A-theory (in which case there could not be a *metaphysically* plausible explanation of the psychological fundamentality of the subjective present), or there could be objective facts about the present that could provide a metaphysically plausible explanation of the psychological fundamentality of the subjective present.

(2) There is no conclusive evidence against the A-theory.

Therefore, there could be objective facts about the present that could provide a metaphysically plausible explanation of the psychological fundamentality of the subjective present.

I shall clarify a number of issues before proceeding. RAA is by no means the only argument that metaphysicians have available to defend the A-theory. Actually, it is not the standard type of argument they use to defend the A-theory, which generally relies on ontological considerations concerning parthood and modality. But since the subjective present determines the experience of temporal becoming which, according to metaphysicians, is the basis of the intuitive power of the A-theory (i.e., it can *explain* such experience) it is convenient to articulate an argument that could justify such intuitive power, and that is the purpose of RAA.

RAA concerns any type of A-theory, because they all agree that there are objective facts about the present. If RAA is sound, then the A-theory should be preferred over competing theories that deny metaphysical significance to the present. As mentioned, one of the most important features of the A-theory, considered to be its main strength by some metaphysicians, is that it is the best account of how we experience time, i.e., our being immediately acquainted with the present and the "feeling" that time passes: a phenomenon that should be explained by our best metaphysical theory of time. Before describing the implications of disambiguating the term 'subjective present' in (1-2) based on the two-phase model of the present (TPMP), I shall briefly comment on how RAA and its supporting arguments (IS and SP) help classify objections against the A-theory.

B-theorists deny that the present is *metaphysically* significant. They claim that all times are on equal existential footing, solely linked by the two place *tenseless* relations *earlier than, later than* and *simultaneous with*. But they acknowledge that the subjective present is *psychologically* significant (or even fundamental) and that it is crucial to explain the way in which we experience the passage of time. So B-theorists also need to clarify and explain why the subjective present plays such a central role in how we experience time.

Although the A-theory has a clear solution to this problem by appealing to something like RAA or simply by stating that the metaphysical significance of the present underlies its psychological significance, the B-theory is the most popular account of the metaphysics of time, in spite of its lack of a clear solution to this problem. Why is the *most intuitive* theory of time regarded as inadequate by many metaphysicians?

It is useful to see how the challenges to the A-theory put forward by B-theorists can be classified as specific challenges to RAA, IS and SP. It seems unreasonable to deny premise (1) of RAA, i.e., the claim that the subjective present (or the experience of the present) is psychologically fundamental, and as mentioned, B-theorists *do not* challenge (1). Actually, an assumption of A-theoretic and B-theoretic assessments of the subjective present is that we are immediately acquainted with it in a psychologically fundamental way, as I am about to explain. However, B-theorists vigorously challenge premise (2) of RAA, as well as arguments IS and SP, and the majority of their challenges focus on SP.

Concerning premise (2) of RAA (and also premise (2) of IS), B-theorists challenge it by offering a tenseless account of temporal indexicals.[111] The 'token-reflexive' account is attractive to B-theorists because they want to prove that there is nothing metaphysically significant about the present, and tense in general, by showing that the truth-conditions for a judgment that an *experience* is present or is happening *now* are simply that the experience be *simultaneous with* the judgment.[112] What determines the truth-conditions for tensed statements, argues the B-theorist, are the tenseless relations *earlier than, later than* and *simultaneous with*. And just as there is nothing metaphysically significant about the indexical 'here', there is nothing metaphysically significant about the indexical 'now'.

There are two problems with the token-reflexive account. First, whether or not a tenseless semantics for temporal indexicals is adequate remains an open question.[113] And second, even assuming that it is adequate, it is not clear that such an account explains the *subjective present*. One may concede that it explains semantic aspects of thoughts and propositions concerning the present. But this semantic account is completely silent about *psychological* issues, which is what is at stake in (2). Many B-theorists concede this

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[111] Versions of this account can be found in Mellor, D. H. (1981) and Smart, J. J. C. (1963 and 1980).

[112] Notice that this token-reflexive solution depends upon *correlating* experiences with simultaneities, something that the TPMP challenges, as I explain in the next section. The account is called 'token-reflexive' because of the characteristics of pure indexicals described in the previous chapter, i.e., it is the expression *itself* that designates a person, time or place.

[113] See Ludlow, P. (1999).

point.[114] So the B-theory's token reflexive account lacks the explanatory power to properly address the issue of the subjective present and does not offer a satisfactory challenge against (2).

More importantly, an assessment of *psychological simultaneity* requires an explanation of the mechanisms that determine how the sensory-motor system manages to have a temporal indexical. I provided such an account with the temporal mental indexical TMD (the indexical alias of the SSP) in the previous chapter. But as the TPMP makes clear, the SSP is not the relevant mechanism to represent *experiences* as present. There are *two cognitive steps* involved in the production of the phenomenon that metaphysicians refer loosely as the 'subjective present' or 'the experience of the present.' I address this issue in the next section.[115] But before proceeding, I shall briefly comment on B-theoretic objections to SP.

With respect to SP, in spite of being the target of abundant objections against the A-theory (particularly premise 2), I will not address any of these objections in detail because of the following reasons. First, SP mainly concerns evidence from physics that is not pertinent to the topic I am interested in, i.e., the subjective present. Second, although a lot of B-theorists claim that the A-theory might be inconsistent with physics because it seems incompatible with Einstein's special and general theories of relativity, the alleged incompatibility of the A-theory with physics is far from being definitely established, and an adequate assessment of this issue requires an enormous amount of research. The status of *time* in physics is a very difficult and open issue and it is a topic that goes beyond the

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[114] See for example Mellor, D. H. (1998), Balashov, Y. (2005) and Mozersky, J. (2006).
[115] What I say in the next section also shows why premise (1) of IS is true.

present study, as I mentioned in chapter 1.[116] I shall now offer my proposal for disambiguating the term ‘subjective present’ (based on the TPMP and the other findings I have analyzed) and illustrate some of its implications for debates in the metaphysics of time.

5.3. Two senses of ‘subjective present’

Exactly how should ‘subjective present’ be construed? A lot of the strength of RAA depends on (1). What happens to (1) when one disambiguates it in terms of the TPMP? Surprisingly, one sense of ‘subjective present’ turns out to be more fundamental, according to the criterion of s-fundamentality because of the following reason. If ‘subjective present’ is defined in terms of *simultaneity*, then the relevant mechanism is the SSP, whose indexical alias is the mental temporal demonstrative, without which the sensory-motor system could not *anchor* the outputs of the clocks or *refer* to moments in time. This satisfies s-fundamentality.

However, if we define ‘subjective present’ in terms of present *experience*, then things change because the relevant mechanism (the PSP) plays a different role. It is not crucial for sensory-motor coordination and the sensory-motor system could, in principle, work without the PSP (this must be the way in which many insects and other animals with less complex nervous systems than the human brain operate). So if ‘subjective present’ is defined in terms of what we experience as present, then premise (1) (and thereby RAA) is questionable, given that the criterion for fundamentality is *s-fundamentality*. This is a noteworthy consequence of disambiguating the term ‘subjective present’ according to the components of the TPMP.

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[116] See for example Barbour, J. (2000) for an explanation of why time might be

Another extremely important consequence of such disambiguation concerns the unquestioned assumption that we are immediately acquainted with the present. This issue actually transcends RAA. It affects A and B-theoretic assessments of the subjective present. For instance, B-theorists that construe the subjective present as judged simultaneity, or the SSP (e.g., Le Poidevin, 2004b and Callender, 2008a) are not offering an empirically sound account of the *experience* or awareness of the present (which requires the longer threshold of the PSP). So accounts of A-theorists that rely on how we experience the present are not vulnerable to criticisms that try to target such experience by focusing on sub-personal judged simultaneity (i.e., the SSP). The unfortunate state of affairs produced by debates in which it is rarely specified what is meant by 'subjective present', 'experienced present' or other related terms (such as *specious present*) produces the impression that authors are talking past each other when they argue about the subjective present.

This issue of the ambiguity surrounding the terms 'present' and 'subjective present' is quite pressing and has been discussed in the literature. Consider what Craig Bourne (2002, 2006) calls 'the present problem.' According to Bourne, A-theorists who are not presentists (i.e., those who accept the existence of past or future times in addition to the present), face the following problem. If one distinguishes an indexical use of 'present' from a metaphysical use of 'present', which Bourne symbolizes as *present*, then judgments about *present* are problematic. Bourne says: "Although we know by immediate acquaintance which time is our own, how can we know that our time is *present*?" (2002, 360)

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dispensable in physics. I say more about SP in section 5.4.

I am not interested in assessing whether or not this is a legitimate metaphysical problem. Rather, I shall focus on Bourne's assumption that we know by *immediate acquaintance* which time is 'present' in the "indexical" sense. *Do we know what time is present by immediate acquaintance?* How to make sense of the indexical use of 'subjective present' in *psychological terms*? Presumably by defining the indexical sense of 'present' in terms of the SSP because what is crucial about the indexical use is that the token (a representation or utterance about 'the present') is *simultaneous* with a moment in time that is designated as the present (ideally the *present*). But before addressing these issues in more detail I would like to mention another instance of this metaphysical debate, in which the assumption of our immediate acquaintance with the present plays a pivotal role.

David Braddon-Mitchell (2004) also tackles the 'present problem' in terms of epistemic access and argues that the presentist and the four-dimensionalist (unlike the no-futurist for whom, according to Braddon-Mitchell, the problem is that the current moment of time may not be *the present*) have a solution to this problem. He says,

> If you are a presentist then the genuine passage of time poses no epistemic problems. For according to the presentist all that exists is the present, so the fact that we know we exist guarantees that we are in the present. The presentist has an objectively characterized conception of the present, but it is one we have simple epistemic access to. If you are a four dimensionalist, it is equally easy to say why we know the current moment of time is the present. For most four dimensionalists have an indexical conception of 'now'. 'Now' just means the moment at which it is thought or uttered. So people at any location in space-time who believe that they exist in the present, will believe correctly. (Braddon-Mitchell, 2004, 199)

How should one construe our "simple epistemic access" to the present that guarantees the solution to the 'present problem' for presentists? It seems that by 'simple' one should understand 'by immediate acquaintance.' And as the evidence in support of the TPMP shows, this is a problematic statement. Similar considerations apply to the indexical conception of 'now' that guarantees, in the four-dimensionalist framework, that *thoughts* correlate with the present. And things get even more complicated when Braddon-Mitchell explores possible solutions for the 'present problem' within the no-futurist framework:

> Suppose that the hyperplane that is the objective present is the only one that contains consciousness. Some hold that consciousness is some by-product of the causal frisson that takes place on the borders of being and non-being. If this were the case it would restore our confidence that the current moment was the present, because it would become a priori in the manner of Descartes' *cogito*. In so far as we know we are conscious, we would know that the current location in space-time was in the present, since as soon as that location in space-time was past, its occupants will be Zombies and thus we would have no awareness. (Braddon-Mitchell, 2004, 201-202)[117]

As I said previously, I am not interested in the metaphysical plausibility of these views. My main concern is the use of experiences, consciousness and thoughts about the present in these debates. Other attempts (besides distinguishing an indexical form a metaphysical use of 'present') have been made in an effort to disambiguate and systematize the term 'present' and its subjective or psychological counterpart the 'subjective present.'[118] But none of them have questioned the assumption that our access to the present, via the subjective present, is *unproblematic* and *immediate*. This is the assumption that I will challenge, based on the TPMP.

I propose that the 'present problem' is best understood as a problem of *coordination*, i.e., how can a theory of time explain the way in which the subjective present is coordinated with the present? An adequate solution to this problem requires an *unambiguous* notion of 'subjective present.' To what exactly is the indexical use of 'present' referring in judgments concerning our present experiences? The meaning of the

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[117] Braddon-Mitchell attributes this view to Peter Forrest, and it is very similar to the view called the 'moving spotlight.'

indexical use of ‘present’ in psychological terms depends on either the SSP or the PSP. Premise (2) of RAA captures the intuition, shared by many metaphysicians, that whatever ‘present’ we are immediately acquainted with (in virtue of whatever psychological mechanism) must correlate with the present (a moment in time with unique metaphysical significance for A-theorists). This problem of coordination seems to be at the core of the ‘present problem.’

Solutions to the present problem disambiguate two senses of ‘present.’ I submit that there is another crucial disambiguation that is required to speak sensibly about coordination between a subjective present with which we are immediately acquainted and the present, i.e., the two senses of ‘subjective present’ (the SSP or the PSP). Suppose one makes this distinction, thereby challenging the notion that our immediate acquaintance with the present is unproblematic.[119] Then there seems to be a dilemma that originates from the following coordination assumption: *the subjective present and the present can only be coordinated by means of simultaneity*.[120]

Otherwise, such coordination would not be *transitive*; objects or events that are in the present would not be coordinated with the subjective present, and *existence* in the present would not be transitive either; the coordination of objects or events as *present* is transitive because of simultaneity. Therefore, based on this assumption, philosophers of time seem to be faced with the following dilemma, which I will call the *subjective present dilemma*.

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[118] See for instance Button, T. (2006).

[119] It is important to highlight that no philosopher of time, including B-theorists, challenges our immediate acquaintance with the subjective present.

[120] I shall not comment on how exactly this could be done, i.e., how the coordinates of a frame of reference in spacetime should be geometrically coordinated with frames of sensory-motor coordination determined by simultaneity. This is clearly a very difficult

The subjective present has to be understood either in terms of sub-personal judged simultaneity or in terms of present experiences of which we are aware (based on the TPMP). If it is understood as judged simultaneity, then metaphysicians could give an empirically robust explanation of the *indexical* use of 'subjective present' in psychological terms, based on the SSP (the SSP anchors the outputs of the clocks and it functions as the *temporal mental demonstrative* of the sensory-motor system). This would have several advantages.

For instance, besides being an empirically accurate interpretation of the term 'subjective present' it would provide metaphysicians with a much-needed way to settle the issue of how long is the duration of the subjective present (up to 250 ms) using scientific evidence rather than intuition or introspection. More importantly, this interpretation defines the subjective present in terms of simultaneity, which is required for coordination. However, this disambiguation would come at a cost because metaphysicians could not use the SSP interpretation to explain how we experience time and how we are aware of present experiences (this explanation requires the longer window of the PSP).

On the other hand, if the 'subjective present' is construed in terms of the PSP, metaphysicians could certainly explain how we experience the present (e.g., how experiences flow and are connected to one another smoothly, how this relates to the experience of passage and the continuity of consciousness and awareness, etc.). This interpretation has many of the advantages of the SSP interpretation because it is an empirically accurate interpretation that provides a range of duration that solves the

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problem that is beyond the scope of my proposal. What I want to emphasize is that problem of the length of the subjective present (from around 500 ms to 3 s). However, this would also come at the considerable cost of not being able to solve the coordination problem, because the PSP account of the subjective present defines it in terms of *phenomenal binding* (a relation that, unlike simultaneity, is *non-transitive*).

So the subjective present dilemma is that the two possible interpretations of 'subjective present' produce undesirable consequences. The SSP interpretation is undesirable because it cannot explain present experiences and awareness, which some metaphysicians take to be essential aspects of our acquaintance with time. And the PSP interpretation is undesirable because it makes the problem of coordination extremely problematic, i.e., how to coordinate the subjective present with the present if the subjective present is not construed in terms of simultaneity?[121] Thus, the choice that metaphysicians seem to be confronted with is one of either solving the coordination problem or explaining how the subjective present relates to our experience of time. Not being able to solve both at the same time is what creates the dilemma.

But is this a false dilemma? Why not solve both? Clearly, the human brain solves both problems since we are able to coordinate action in terms of the SSP and experience the world in terms of the PSP. It is true that the brain solves both issues (i.e., how to coordinate action and interconnect experiences into a continuous flow). But this does not help at all in eliminating the dilemma. What is needed to dissolve the dilemma is to show that the subjective present can be consistently characterized both in terms of simultaneity

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simultaneity, however it is determined, is *essential* for coordination.

[121] More specifically, coordination depends upon transitivity, and the relation that frames the PSP is not transitive—if it were *all* past and future experiences would be related by the PSP. So if one wants to have a scientifically informed account of the subjective

(the SSP) and phenomenal binding (the PSP). In other words, to solve the dilemma it needs to be demonstrated that the subjective present can be characterized in terms of a relation that is both transitive and non-transitive, which seems impossible.

But why is not the fact that the brain solves the problems of coordination and continuous experience *enough* to show that this is a false dilemma? Because pointing at facts does not help solve dilemmas. Take for instance the dilemma presented by determinism and free will. The fact that we live in a world that seems to be deterministic (i.e., all events are causal events that depend on previous physical configurations) plus the fact that we seem to have free will in the *same deterministic world* does not help solve the following dilemma. Either we accept that we have no free will and everything is predetermined or we accept that our actions are not causally determined and thus, not really under our control as *causes* of actions. Likewise, the fact that the brain is responsible for determining the SSP and the PSP does not help solve the subjective present dilemma.

But there is a more perspicuous way of showing why the SSP and the PSP are not easily reconcilable, i.e., one cannot capture their characteristics by means of a single term 'subjective present' and one needs to always distinguish them. This clearer way of appreciating the sharp distinction between the SSP and the PSP requires an assessment of the type of cognitive possibilities that they generate. As I mentioned in the introduction to this chapter, the outputs of the circadian clock provide a *phase-based* representation space of possibilities for action-coordination and the outputs of the stopwatch provide an *aperiodic interval-based* representation space for action-coordination. These

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present, one must accept the consequence that if the subjective present is construed in representation spaces of possibilities allow animals and humans to be successful in performing a multiplicity of tasks by interpreting their metric information in different ways, thereby eliminating possibilities that would not lead to the completion of goals.

But these phase and interval representation spaces of possibilities are both dependent on the anchoring performed by the SSP (the temporal mental indexical of the sensory-motor system). This has profound implications, the most important of which is that one can interact with the environment (e.g., perceive, navigate, coordinate action) without being aware of the metric information stored in the representation spaces of possibilities for action. Allow me to elaborate on this point.

As I mentioned in chapter 4 (particularly section 4.4.1.), the distinction between unconscious and conscious information processing can also be explained in terms of action-outcome (A-O) associations based on declarative memory for conscious information, and stimulus-response (S-R) associations based on procedural memory for unconscious information. When animals are trained, A-O associations can become S-R associations, and the same thing happens with humans. A familiar example of this is when one learns how to ride a bike. Most of the cognitive processes involved in motor-coordination (like the anchoring of the outputs of the clocks by the SSP) occur at the sub-personal or unconscious level. But when one is learning a challenging *coordination task*, a lot of *attention*, and thereby conscious A-O associations are required to calibrate appropriate responses to stimuli.

Picture yourself as a kid, when you learned how to ride a bike. There you are, stumbling, struggling, thinking you will never be able to succeed and most importantly,

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terms of the PSP, coordination with the present seems impossible.

focusing on how your legs and hands should be moving to keep your body in balance. People keep telling you that some day you will not even have to *think about* how your body should be positioned in order to keep yourself in balance and that you will be able to focus on other things, like how beautiful the park is. And then one day, as people promised, you really stop focusing on your body and start enjoying more and more taking rides in the park. What happened?

What happened is that the "machinery" of your sensory-motor system took over. The machinery (which includes the metric representation spaces of possibilities that depend on the clocks and the SSP) is now finely tuned. Now your *experience* of riding the bike is completely different. You can literally forget about your body coordination and enjoy the sound of birds singing, the color of the trees, the breeze, and so on. It is the PSP that is allowing you to make smooth transitions between these experiences, melting them into a single flow by means of *phenomenal binding*.

The PSP was doing this before you learned how to ride the bike: your experiences of suffering, stumbling and being uncertain about whether or not you were doing things right were all connected in the same way by phenomenal binding. This is important, because you never experienced the *discreteness* of the information-processing happening at the SSP (the cross-modal simultaneity window) and its relation to other complex sensor-motor processes. But this illustration of learning how to ride a bike shows the drastic difference between how the SSP and the PSP *immediately acquaint* an individual to *sensory-motor information* and *experiences* respectively. These are two very different *cognitive steps*.

The SSP anchors representation spaces of possibilities that determine sensory-motor coordination, and immediately acquaints an individual with *metric features* of the environment. The PSP creates *phenomenal units* of experiences and allows for smooth transitions between these experiences, of which the individual is aware. The first step is one of coordination with the environment by means of metric representation; the second is one of higher cognitive integration, in which attention selects experiences through awareness. The cognitive possibilities involved in these two steps (one concerning coordination and the other experience) could not be more different. One confronts a subject with options for action based on metrically structured representations; the other with a set of experiences that the subject can attend to at a given time. As far as information is concerned, these could be two different worlds.[122]

It is because of these reasons that I shall challenge the assumption that we are immediately acquainted with the present. As mentioned, no one in the metaphysics of time literature challenges this assumption (i.e., that we are immediately acquainted with the subjective present—or with the present by means of some sort of subjective present). Both A and B-theorists agree on this.

Disambiguations or clarifications of this kind certainly have implications for metaphysical debates. I already mentioned two such implications: a) the subjective present is s-fundamental if interpreted as the SSP but not s-fundamental if interpreted as

[122] The SSP and the PSP concern two different worlds of information, one in which metric information is fundamental, the other in which attention is fundamental. But there is a relationship between the two that I shall formalize in terms of the following *correlation rule* between the SSP and the PSP: *The more familiar the subject is with a situation, the more degrees of freedom the PSP has to phenomenally bind diverse experiences*. Or equivalently, *the less challenging a sensory-motor task, the more degrees of freedom the PSP has to create possible configurations of bound experiences*.

the PSP and b) the subjective present dilemma. But other implications are possible, for instance with respect to centered worlds and essentially indexical information. I will not work out these implications in detail here. Rather, I will mention a challenge to "immediate acquaintance" that is similar to the one I am proposing, which concerns Frank Jackson's knowledge argument. Martina Nida-Rümelin argues,

> It is common to formulate Mary's new knowledge in terms of Thomas Nagel's famous locution of knowing what it's like: Mary does not know (while living in her black-and-white environment) what it is like to see colors and she learns what it is like to see colors only after her release. But this common way to put the point may lead to a confusion of (a) mere acquaintance with kinds of color experiences by having and remembering them and (b) knowledge about what kind of color experience other subjects have at a given occasion, and it may thereby lead to a failure to distinguish two steps of epistemic progress that Jackson's Mary takes at once. (Nida-Rümelin, 2002)

In order to motivate this distinction between (a) and (b), Nida-Rümelin (1996, 1998) presents a thought experiment in which a subject *Marianna* (like Mary) is a brilliant color scientist that has lived all her life in a black and white environment. But unlike Mary (who gets acquainted with color by leaving the room and seeing the blue sky and the color of objects she knew about before without knowing what it is like to see them), Marianna gets acquainted with color by moving to another room with arbitrarily colored objects, like abstract paintings.

In this odd environment, Marianna is immediately acquainted with colors and knows what it is like to see them. She might be looking intently at a particular patch of red, enjoying the experience of what it is like to see red for the first time. But she is not able yet to know that the color she is acquainted with is the color that other people experience as red. In other words, she is unable to *connect* her previous knowledge of color to the experiences of color that she is now immediately acquainted with. Only when she leaves the arbitrarily colored room and sees the blue sky, red apples, and so on, can she acquire knowledge about the experiences of other people.

So only when Marianna sees the sky, and so on, can she *apply* the phenomenal information that she was immediately acquainted with at the room with abstract paintings. And as Nida-Rümelin says, this cognitive step concerning how to apply phenomenal information is not adequately described in terms of "knowing what it is like". Rather, the process of "immediate acquaintance" with color in the case of Mary involves a cognitive operation by means of which information is correlated in *two steps*. This is a distinction that gets blurred in Jackson's original formulation of the thought experiment.[123]

The distinction that I am suggesting, based on the TPMP, is similar to the one Nida-Rümelin makes because both distinctions challenge the assumption that immediate acquaintance involves a single cognitive step of immediate access to information. In the case of the TPMP, this assumption is challenged by showing that we are not immediately acquainted with a single representation or experience called the 'subjective present.' Rather, this notion can be disambiguated in terms of coordination (the SSP) or phenomenal experiences (the PSP). A difference between Nida-Rümelin's distinction and

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[123] For an explanation of the implications of this distinction for the individuation of so-called centered-worlds and the analysis of essentially contextual information see Stalnaker, R. C. (2008), particularly his discussion of indistinguishability. The most important implication of this distinction, according to Stalnaker, is that the phenomenal concepts of the first cognitive step (the room with arbitrarily colored objects) *may not designate rigidly*, as is assumed. In other words, the same phenomenal concept might apply to different experiences in different possible worlds. Addressing the issue of whether the TPMP has similar implications is beyond the scope of this dissertation. But an approximate gloss of this distinction would be that the same experience framed by the PSP might be coordinated *differently* by the SSP in different environments. See

the TPMP's distinction is that the TPMP is motivated by scientific evidence, which is an advantage because it is suitable for naturalistic explanations. In the next section, I explain how A-theorists may benefit from the TPMP distinction.

5.4. Implications of the SSP for the A-theory

What are the consequences of disambiguating claims about our immediate acquaintance with the subjective present (based on the TPMP) for debates in the metaphysics of time, particularly concerning the plausibility of the A-theory and the force of the RAA argument? I submit that the distinction I am proposing (the SSP and the PSP) strengthens the A-theory by giving it a clear and empirically robust way of characterizing the uniqueness and fundamental character of the subjective present, if construed in terms of the SSP. Construing 'subjective present' in terms of the SSP also clarifies how the subjective present coordinates with the present and why such coordination has metaphysical significance. I proceed to explain these claims.

It is difficult to prove that a widely held philosophical view is wrong, and the B-theory is no exception. I will not try to settle which theory of time is ultimately true (a task that far exceeds the scope of my dissertation). Rather, I shall explain how disambiguating the term 'subjective present' can lead to philosophical progress with respect to debates in the philosophy of time by making the case for the A-theory stronger. Progress can be made towards determining which metaphysical views are more plausible than others by disambiguating the most important philosophical terms that metaphysicians rely upon and by interpreting relevant scientific findings. Precision and

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particularly the correlation rule of footnote 20 of this chapter to appreciate how familiar sensory-motor tasks allow for many degrees of freedom at the PSP level.

scientific evidence can help determine which philosophical views should be endorsed, modified or even abandoned.

B-theorists often accuse A-theorists of not paying enough attention to scientific evidence (mostly physics), which makes the A-theory, B-theorists claim, an imprecise and anthropocentric view of time.[124] B-theorists also criticize the metaphoric and vague language that some A-theorists use to support their arguments, e.g., 'the flow of time', 'temporal becoming', 'the presence of experience', etc.[125]

B-theorists claim that the B-theory dispenses with these metaphoric and anthropocentric conceptions of time, which makes it a more precise account of time that comports with scientific findings. These shortcomings of the A-theory make B-theorists believe in the B-theory so fervently, that they are willing to dispense with the very compelling and fundamental distinction between past, present and future. In other words, B-theorists believe that one of the *most essential features* of our psychology (i.e., our immediate acquaintance with the distinction between past, present and future) is an illusion with *no metaphysical significance* largely because we have no precise and scientific means of making sense of it.

It is with respect to these issues (i.e., lack of precision and ignorance of scientific evidence) that the TPMP distinction is useful for defenders of the A-theory. More specifically, the distinction between the SSP and the PSP addresses directly the criticisms

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[124] J. J. C. Smart (1949, 1963, 1980 and 2006) has challenged the A-theory based on these grounds, and one can find this sort of challenge in many B-theoretic accounts of time.

[125] See for instance Callender (2008a), who says: "Contemporary analytic philosophers of time typically point in a perfunctory way to various stock mental experiences as a justification of their byzantine metaphysical systems. One is told that we feel time pass or that the present is sensed as special—as if we know exactly what that means—and that we can only explain this through a tensed metaphysics." (2008, 340)

that B-theorists often make against the A-theory by providing a clear and scientifically based model of the present in terms of two cognitive steps. The metaphysical significance of the components of the TPMP can be assessed independently, without using vague language or metaphors.

The most important implication of the TPMP for the metaphysics of time is that 's-fundamentality' and the subjective present dilemma demand a particular interpretation of RAA that *elucidates* and *strengthens* the case for the A-theory. This interpretation construes the term 'subjective present' as the SSP. As I am about to explain, the SSP provides a scientifically based notion of the subjective present that makes RAA quite compelling, and gives the A-theorists a clearer and empirically sound way of answering to the criticisms made by B-theorists.

I mentioned in the previous section that if one adopts the notion of 's-fundamentality' as the criterion for fundamentality, then premise (1) of RAA (i.e., that the subjective present is psychologically fundamental and enjoys a privileged intuitive status) is true if one interprets 'subjective present' as the SSP, but questionable if one interprets it as the PSP. I shall elaborate on why this is the case.

S-fundamentality imposes the very restrictive requirement that a representation must be such that the sensory-motor system could not individuate contents, refer to stimuli and be reliable without it. The SSP is fundamental for the outputs of the clocks to be anchored, acquire content and be susceptible of reference by the sensory-motor system. This allows the sensory-motor system to determine phase-based and interval-based representation spaces of possibilities for action. And this is the reason why the SSP is *s-fundamental*. But things are very different with the PSP. The sensory-motor system can work perfectly well without it. This is illustrated by the principle I described in footnote 20 of this chapter, that *the more familiar the subject is with a situation, the more degrees of freedom the PSP has to phenomenally bind diverse experiences.* The machinery of the SSP and the sensory-motor system works independently from the flow of experiences that the PSP binds, and this is why the PSP is not s-fundamental.

Adopting s-fundamentality comes at a price. A-theorists cannot refer to consciousness, flow of experiences or our awareness or experience of the present to justify their views (the SSP operates at the sub-personal, unconscious level). But the price is worth paying. A less metaphorical notion of 'subjective present' becomes available for A-theorists. According to this interpretation, one is *not* immediately acquainted with the subjective present in terms of experiences and their "flow."

However, in exchange one gets a more *precise* notion of acquaintance: one in which simultaneity plays a central role. By means of this different notion of 'acquaintance', demonstrative thoughts about phases of the circadian clock and moments of intervals (the most fundamental forms of time representation) *anchor* possible scenarios for action, which allows the sensory-motor system to calibrate and update all sorts of information. This crucial cognitive process would be left unexplained if 'acquaintance' were interpreted in terms of the PSP.

Thus, the A-theory is strengthened and enhanced with a scientifically robust explanation of the fundamentality of the subjective present, which is *directly related to the outputs of the clocks*. And there is something very important about the SSP's compliance with s-fundamentality, which is that it determines how *coordination* with a privileged moment in time (the present) is possible. Premise (1) of RAA relates to (2) by means of fundamentality because (2) states that the psychological fundamentality of the subjective present should lead us to believe that there are objective facts about the present.

S-fundamentality demands that 'subjective present' be interpreted as the SSP, which relates stimuli in terms of simultaneity. I will now explain why (2) is true if one construes 'subjective present' as the SSP, but not if it is construed as the PSP. To fully appreciate this, I must elaborate on the implications of the subjective present dilemma for RAA. Premise (2) demands coordination between the subjective present and the present, which in turn requires a solution to the 'present problem.' Otherwise it is not clear how the relationship between the subjective present and the present should be construed. I explained in the previous section that the only way to solve the 'present problem' is in terms of the SSP because simultaneity is *indispensable* for coordination. I shall now explain this in more detail.

What is needed to successfully solve the 'present problem' is an *invariant notion* of 'subjective present' that complies with the requirements of an indexical (a mental demonstrative) that is *constantly, systematically and uniquely* correlated to the present. This means that the SSP would not only serve as the 'pointer' that indicates to the sensory-motor system which moment is now (i.e., which phase of the circadian clock or moment of an elapsed interval emulated by the stopwatch is 'now'). The SSP would also correlate with a unique moment *in time* with special metaphysical status, i.e., the present.

By an *invariant* subjective present, I mean that its length, constraints and properties do not change. This condition is met by the upper threshold of the SSP (not larger than 250 ms) and by the fact that the SSP *always* relates stimuli in terms of simultaneity. The

PSP also has a constant upper threshold, but it is significantly larger, and it plays no role in the anchoring of the outputs of the clocks. More importantly, the relation that characterizes the PSP varies in *how* it binds experiences: it is non-transitive, which means that experiences will be *sometimes* bound by phenomenal binding and sometimes not. Crucially, this will depend on arbitrary constraints, such as the subject's attention capacity and what she is attending to.

How should the correlation between the subjective present and the present moment (which in physics could be infinitesimal or arbitrarily short) within a frame of reference be construed is beyond the scope of my proposal—it could probably involve some sort of scaling function that preserves simultaneity, but this is a very difficult topic. However, the only claim I am making (the only one I need for the SSP's invariance) is that simultaneity is crucial for such coordination which, as I am about to explain, is what makes such coordination *systematic*.

By a 'systematic' coordination, I mean that the subjective present and the present must always be synchronous. This requires that the subjective present should always be construed in terms of simultaneity. Otherwise (as in the case of the PSP) the coordination will not be *transitive* and it would be very problematic to establish synchrony between the subjective present and the present. The SSP always relates information in terms of simultaneity, and the synchrony between the SSP and the present means that the coordination is constant and unique because the SSP is always pointing at the present moment and *only* at the present moment.

Construing coordination in this way helps explain why premise (2) states that the psychological fundamentality of the subjective present should serve as evidence of the privileged *metaphysical* status of the present moment. The SSP (as anchor of the metric outputs of the clocks) *coordinates* information from the clocks with information from the environment. Such coordination, as I explained in previous chapters, produces *highly reliable* cognitive processes that lead to *successful* behavior. A very relevant aspect of such coordination is that the information that the SSP anchors is about metric features of the environment. There is *conditional dependency* between features of the environment (periods and intervals) and the metric outputs of the clocks. These representations *guide* us (and other creatures) in our daily activities and without them we could not interact with the world.

B-theorists say that there is no distinction between present, past and future in the real world. How would they explain the coordination of metric information I just described? Based on my proposal, A-theorists now have a *scientifically informed* way of answering this question: the SSP coordinates information in a successful way because it correlates with the present moment (a metaphysically unique moment in time) via simultaneity. This explains the conditional dependency between changes in metric features of the environment and how the clocks (and other sensory-motor mechanisms) update information accordingly.

What should B-theorists say if they think that the present is an illusion? It is not clear that such *cognitive* coordination-processes that have been scientifically established even make sense within a B-theoretic framework. This is a significant issue that favors the A-theory and strongly suggests that premise (2) of RAA is true. Of course, this issue of coordination is not definitive evidence that the B-theory is false. But at least it shows how problematic the B-theory is when the scientific evidence one is concerned with involves cognitive processes.

However, not everything is good news for the A-theorists. Adopting the interpretation of 'subjective present' that I am suggesting (i.e., the SSP) comes at a price. Considerations concerning coordination seriously challenge the claims of some A-theorists that appeal to consciousness and experience to explain how we are acquainted with the present because, as mentioned, coordination in terms of the PSP is *not* invariant and systematic. But, once again, this might be a price worth paying. By interpreting 'subjective present' as the SSP, A-theorists have a precise way of defending premise (2) of RAA and, more generally, of addressing issues concerning coordination, such as the 'present problem.'

Based on the previous explanation, I propose that if by 'subjective present' we mean the SSP, then RAA is a sound argument. Otherwise, the notion of 'subjective present' is problematic, and premises (1) and (2) are false. But what about arguments IS and SP? Are these sound arguments as well? I submit that the most plausible answer is *yes*. With respect to IS, the fact that the coordination between the SSP and the present (and cognitive coordination processes in general) only makes sense within the framework of the A-theory, shows that IS is sound (i.e., the A-theory is the most intuitive theory of time because it can explain the psychological fundamentality of the present and this should lead us to believe that there are objective facts about the present, which is an obvious and commonsensical belief).

SP concerns undecided empirical issues. More specifically, the adequacy of the A-theory depends on scientific findings from physics concerning the nature of spacetime. It is worth emphasizing that deciding the case between the A and B theories might be one of the most colossal tasks in metaphysics because the nature of spacetime continues to be a major conundrum in physics. There are proposals for A-theoretic approaches to spacetime in physics.[126] But clearly the challenges are still very significant. However, as things stand now, SP should be considered as a sound argument for the following reasons.

An important reason to favor the A-theory is that the physical evidence for the B-theory (which is what most B-theorists appeal to when they defend their views on time) is still inconclusive. Why opt for the B-theory's *extremely* unintuitive and "detached" view of time, which dispenses with the present, if the evidence is still incomplete? The inconclusiveness of the physical evidence means that the A and B theories are still "waiting for a verdict" from whatever turns out to be the true theory of spacetime, which gives support to SP.

But there is a positive reason to favor the A-theory, which IS captures. The A-theory is more intuitive (and plausible) than the B-theory because, as I argued, it can explain cognitive processes of coordination that lead to successful action using *scientific evidence* from cognitive science. This should appease the B-theorists' qualm that A-theorists pay little attention to scientific evidence. And since RAA and its supportive arguments (IS and SP) seem to be sound, then we should believe that there are objective facts about the present.

I shall conclude with a few remarks about why the coordination between the subjective present and the present elucidate and make more precise the notion of

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[126] See Dowker, F. (2006).

"temporal becoming." The distinction between present, past and future must be interpreted in terms of coordination, not of "flow". But it is crucial to understand that what is coordinated are not *abstract* phase or interval-based representation spaces of possibilities. Rather, the SSP anchors sensory-motor representations that indicate to an animal or a human *what to do next*. These anchoring sharply distinguishes the present from the past and the future via the temporal mental indexical—the mental equivalent of the indexical 'now.' And the sensory-motor system uses this temporal anchoring for *everything* it does (e.g., storing information in a specific type of memory, updating information, calibrating metric information from different sources, etc.).

Another way of saying this is that the representation spaces of possibilities that are *anchored* by the SSP *confront an agent with options for immediate action*. They confront an agent with an *opportunity*, or a *predicament* rather than with an abstract *configuration space*. The fact that these are representation spaces for *action* shows that the distinction between past, present (the SSP) and future is essential for *information to be anchored*. This is exactly how the metric outputs of the clocks (and other metric information in the sensory-motor system) acquire specific content. The consequences of acting or failing to act are very real and so, it is plausible to say that the distinction between past, present and future is very real. This is the intuition that RAA formalizes and that the SSP makes more precise.

5.5. Main conclusions of my dissertation

As I said in chapter 1, one of the main aims of my thesis was to introduce to the philosophical literature the relevant scientific findings concerning our immediate acquaintance with time. This goal was accomplished by reviewing the two most relevant findings in the psychological literature on our immediate acquaintance with time: the findings on the representational outputs of the circadian clock and the stopwatch and the findings on simultaneity windows.

Another important objective of this thesis that I mentioned in chapter 1 was to explain these findings rigorously and in detail. I criticized some philosophers for mentioning scientific evidence too quickly and with little attention to the details and implications of the experimental evidence they use. I achieved the goal of providing a rigorous and detailed analysis of the findings I used by studying them with a theoretical framework that highlights the basic features of the mechanisms and representations that have been confirmed by these findings.

Aspects of this framework are based upon the work of cognitive scientists, such as the distinction between periodic and interval timing. Other aspects of this framework are original contributions of my dissertation, such as the classification of clocks in terms of the distinction between periodic and interval timing, the characterization of the representational outputs of the clocks as analog-metric representations and the two-phase model of the present.

Explaining the philosophical relevance of these findings was another important goal of my thesis. This challenge was met by answering specific philosophical problems. For example, with respect to the old problem of why is it that we are immediately acquainted with the duration of events (information that is metric in nature) I explained that the outputs of the clocks have metric structure and provided criteria in order to characterize them as analog continuous representations. These representations are our most fundamental way of representing duration.

Concerning the issue of the length of the specious present (a recurring topic in the philosophy of time) I provided evidence for two different types of specious present (the sensorial specious present and the phenomenal specious present) and offered a model (the two-phase model of the present or TPMP) to describe how these types of present may interact. But the most important philosophical implications of the TPMP concern issues in the metaphysics of time.

The TPMP challenges the widely held assumption that we are immediately acquainted with the subjective present because it reveals that such assumption is ambiguous. Acquaintance can be construed in two ways, one in terms of sensorial representation and the other in terms of experience. The first sense is more fundamental and this, as I explained in this chapter, has significant repercussions for issues in the metaphysics of time, particularly concerning the plausibility of the A-theory.

Finally, I have also wanted to encourage philosophers, including metaphysicians, to appreciate and evaluate not only evidence from the natural sciences, but also from cognitive science. Hopefully, the amazing experiments on the clocks and simultaneity windows that I reviewed will entice philosophers to approach psychological findings with a more receptive mind. The experiments that cognitive scientists conduct daily have implications for philosophy. It is the task of the philosopher to be vigilant and look for those findings that could lead to significant philosophical progress.

Bibliography

Aristotle (1980) *Physics* (Grinnell, Iowa: The Peripatetic Press).

Augustine (1961) *Confessions* (Harmondsworth, UK: Penguin).

Baker, L. R. (1979) “On the mind-dependence of temporal becoming” *Philosophical and Phenomenological Research*, 39: 341–357.

Balashov, Y. (2005) “Times of Our Lives: Negotiating the Presence of Experience” *American Philosophical Quarterly*, 42: 295-309.

Barbour J. (2000) *The End of Time* (New York, NY: Oxford University Press).

Bermúdez, J. L. (1995) “Nonconceptual Content: From Perceptual Experience to Subpersonal Computational States” *Mind and Language*, 10(4): 333-369.

Bermúdez, J. L. (2003) *Thinking without Words* (New York, NY: Oxford University Press).

Bhattacharjee, Y. (2006) “A Timely Debate About the Brain” *Science* 3-311(5761): 596-598.

Blachowicz, J. (1997) “Analog Representation Beyond Mental Imagery” *The Journal of Philosophy*, 94(2): 55-84.

Block, N. (1995) “On a confusion about the function of consciousness.” *Behavioral and Brain Sciences*, 18: 227-47.

Bourne, C. (2002) “When Am I? A Tense Time for Some Tense Theorists?” *Australasian Journal of Philosophy*, 80(3): 359-371.

Bourne, C. (2006) *A Future for Presentism* (Oxford, UK: Oxford University Press).

Braddon-Mitchell, D. (2004) “How do we know it is now now” *Analysis*, 64(3): 199-203.

Broad, C. D. (1923) *Scientific Thought* (Bristol, UK: Thoemmes Press/Routledge; Reprinted 1993).

Brouwer L. E. J. (1907) “On the Foundations of Mathematics” in *Collected Works* (Amsterdam, The Netherlands: North-Holland Publishing Company; 1975; Vol. 1, pp. 13-52).

Button, T. (2006) “There’s no time like the present” *Analysis*, 66(2): 130-135.

Callender, C. (2008a) “The Common Now” *Philosophical Issues*, 18: 339-361.

Callender, C. (2008b) "Review of Robin Le Poidevin's *Images of Time*" *Notre Dame Philosophical Reviews.*

Campbell, N. R. (1928) *An account of the principles of measurement and calculation* (London, UK: Longmans, Green).

Carnap, R. (1967) *The Logical Structure of the World* (Berkeley, CA: University of California Press).

Casati, R. (2003) "Representational Advantages" *Proceedings of the Aristotelian Society*, 281-298.

Cheng, K. and Roberts, W. (1991) "Three psychophysical principles of timing in pigeons" *Learning and Motivation,* 22: 112-128.

Cheng, R. K., MacDonald, C. J., & Meck, W. H (2006) "Differential effects of cocaine and ketamine on time estimation: Implications for neurobiological models of interval timing" *Pharmacology Biochemistry and Behavior*, 85: 114-122.

Cheng, R. K., Hakak, O. L. and Meck, W. H. (2007) "Habit formation and the loss of control of an internal clock: inverse relationship between the level of baseline training and the clock-speed enhancing effects of methamphetamine" *Psychopharmacology*, 193: 351-362.

Chisholm, R. (1990) "Referring to Things That No Longer Exist" in J. Tomberlin (ed.), *Philosophical Perspectives 4 (Action Theory and Philosophy of Mind)* Atascadero, CA: Ridgeview, 545-556.

Church, R. M. and Gibbon, J. (1982) "Temporal generalization" *Journal of Experimental Psychology: Animal Behavior Processes,* 8: 165-186.

Church, R. M., W. H. Meck, W. H., Gibbon, J. (1994) "Application of scalar timing theory to individual trials" *Journal of Experimental Psychology: Animal Behavior Processes*, 20: 135– 155.

Clark, A. (2000) *A Theory of Sentience* (New York, NY: Oxford University Press).

Clayton, N. S., & Dickinson, A. (1998) "Episodic-like memory during cache recovery by Scrub-jays" *Nature*, 395: 272-274.

Clayton, N. S., Yu, K. S., and Dickinson, A. (2003a) "Interacting cache memories: Evidence of flexible memory use by scrub jays" *Journal of Experimental Psychology: Animal Behavior Processes*, 29: 14-22.

Clayton, N. S., Bussey, T. J., and Dickinson, A. (2003b) "Can animals recall the past and plan for the future?" *Nature reviews Neurosciences*, 4: 685-691.

Clayton, N. S., Emery, N. J., and Dickinson, A. (2006) "The prospective cognition of food caching and recovery by western scrub-jays (*Aphelocoma californica*)" *Comparative Cognition & Behavior Reviews*, 1(1): 1-11.

Concannon, P. W., Parks, J. E., Roberts, P. J., Tennant B. C. (1992) "Persistent free-running circannual reproductive cycles during prolonged exposure to a constant 12L:12D photoperiod in laboratory woodchucks (*Marmota monax*)" *Laboratory Animal Science*, 42: 382-391.

Cordes, S., Gelman, R., Gallistel, C. R. and Whalen, J. (2001) "Variability signatures distinguish verbal from nonverbal counting for both large and small numbers" *Psychonomic Bulletin & Review,* 8: 698–707.

Coull, J. T., Vidal, F., Nazarian, B., Macar, F. (2004) "Functional anatomy of the attentional modulation of time estimation" *Science* 303: 1506– 1508.

Cummins, R. (1996) "Systematicity" *The Journal of Philosophy*, 93: 591-614.

Cummins, R., Blackmon, J., Byrd, D., Poirier, P., Roth, M. and Schwarz, G. (2001) "Systematicity and the Cognition of Structured Domains" *Journal of Philosophy*, 98: 167-185.

Dainton, B. (2000) *Stream of Consciousness: Unity and continuity in conscious experience* (New York, NY: Routledge).

Dainton, B. (2004) "The Self and the Phenomenal" *Ratio*, 17(4): 365-389.

Dehaene, S. (1997) *The Number Sense* (New York, NY: Oxford University Press).

Dennett, D. (1991) *Consciousness Explained* (Boston, MA: Little, Brown, and Co.).

Dixon, N. and Spitz, L. (1980) "The Detection of Auditory Visual Desynchrony" *Perception*, 9: 719–721.

Dowker, F. (2006) "Causal sets as discrete spacetime" *Contemporary Physics*, 47(1): 1-9.

Dresner, E. (2004) "Over-Assignment of Structure" *Journal of Philosophical Logic*, 33: 467-480.

Dretske, F. (1981) *Knowledge and the Flow of Information* (Cambridge, MA: MIT Press).

Dunlap, J. C. and Loros, J. J. (2006) "How Fungi Keep Time: Circadian System in *Neurospora* and Other Fungi" *Current Opinion in Microbiology* 9(6): 579-587.

Eagleman, D. and Holcombe, A. (2002) "Causality and the Perception of Time" *Trends in Cognitive Science*, 6: 323-326.

Egan, F. (1995) "Computation and Content" *The Philosophical Review*, 104: 181-203.

Emlen, S. T. (1975) "Migration: Orientation and navigation" in D. S. Farner and J. R. King (eds), *Avian Biology* (New York, NY: Academic, 129-219).

Fleissner, Gerta, Schuchardt, K., Neumann, D., Bali, G., Falkenberg, G. and Fleissner, Guenther (2008) "A Lunar Clock Changes Shielding Pigment Transparency in Larval Ocelli of *Clunio marinus*" *Chronobiology International*, 25(1): 17-30.

Fodor, J. (2007) "Revenge of the Given" in B. P. McLaughlin and J. Cohen (eds), *Contemporary Debates in the Philosophy of Mind* (New York, NY: Basil Blackwell pp. 105-116).

Fujisaki, W., Shimojo, S., Kashino, M., and Nishida, S. (2004) "Recalibration of Audiovisual Simultaneity" *Nature Neuroscience*, 7: 773-778.

Gallistel, C. R. (1990) *The Organization of Learning* (Cambridge, MA: MIT Press).

Gallistel, C. R., and Gelman, R. (1992) "Verbal and preverbal counting and computation" *Cognition,* 44: 43-74.

Gallistel, C. R. (2008) "Learning and Representation" in R. Menzel and J. Byrne (eds), *Learning and Memory: A Comprehensive Reference* Vol. 1 (New York, NY: Academic Press, pp. 227-242).

Gallistel, C. R. and King, A. P. (2009) *Memory and the Computational Brain: How Cognitive Science Will Transform Neuroscience* (New York: Blackwell/Wiley).

Gibbon, J. (1977) "Scalar expectancy theory and Weber's law in animal timing" *Psychological Review*, 84: 279-335.

Gibbon, J., Church, R. M., Meck, W. H. (1984) "Scalar timing in memory" *Annals of The New York Academy of Sciences*, 423: 52– 77.

Giere, R. (1999) *Science Without Laws* (Chicago, IL: University of Chicago Press).

Gill, F. B. (1988) "Trapline foraging by hermit hummingbirds: Competition for an undefended renewable resource" *Ecology*, 69: 1933-1942.

Golden, S. S. and Canales, S. R. (2003) "Cyanobacterial circadian clocks-timing is everything" *Nature Reviews Microbiology*, 1:191-199.

Goldman, A. I. (1987) "Cognitive Science and Metaphysics," *The Journal of Philosophy*, 84: 537-544.

Goldman, A. I. (1989) "Metaphysics, Mind, and Mental Science," *Philosophical Topics*, 17: 131-145.

Goldman, A. I. (2007) "A Program for "Naturalizing" Metaphysics with Application to the Ontology of Events" *The Monist*, 90(3): 457-479.

Goodman, N. (1951) *The Structure of Appearance* (Cambridge, MA: Harvard University Press).

Goodman, N. (1976) *Languages of Art* (Indianapolis, IN: Hackett).

Graff, D. (2001) "Phenomenal Continua and the Sorites" *Mind*, 110(440): 905-935.

Hardin, C. L. (1988) *Color for Philosophers: Unweaving the Rainbow* (Indianapolis, IN: Hackett).

Haugeland, J. (1981) "Analog and analog" *Philosophical Topics*, 12: 213-26.

Heil, J. (2005) "Dispositions" *Synthese*, 144: 343-356.

Hiatt, J. F. and Kripke, D. F. (1975) "Ultradian Rhythms in Waking Gastric Activity" *Psychosomatic Medicine*, 37(4): 320-325.

Ivry, R. B. and Schlerf, J. E. (2008) "Dedicated and intrinsic models of time perception" *Trends in Cognitive Science*, 12(7): 273-280.

James, W. (1890) *The Principles of Psychology I-II* (London, UK: Macmillan).

Kant, I. (2000) *Critique of Pure Reason* (New York, NY: Cambridge University Press).

Kaplan, D. (1989a) "Demonstratives" in Almog, J., Perry, J. and Wettstein, H. (eds.) *Themes From Kaplan* (New York, NY: Oxford University Press).

Kaplan, D. (1989b) "Afterthoughts" in Almog, J., Perry, J. and Wettstein, H. (eds.) *Themes From Kaplan* (New York, NY: Oxford University Press).

Karmarkar, U. R. and Buonomano, D.V. (2007) "Timing in the absence of clocks: encoding time in neural network states" *Neuron*, 53: 427–438.

Killeen, P. (1975) “On the temporal control of behavior” *Psychological Review*, 82: 89-115.

King, A. (2005) “Multisensory Integration: Strategies for Synchronization” *Current Biology*, 15: 339-41.

Kripke, D. F. (1972) “Perceptual Deprivation, REM Sleep, and an Ultradian Biological Rhythm” *Psychosomatic Medicine*, 34: 221-234.

Kripke, D. F. (1973) “Ultradian Rhythms in Sleep and Wakefulness” in E. D. Weitzman (ed), *Advances in Sleep Research* (New York: NY: Spectrum, 305-325).

Kripke, S. (1980) *Naming and Necessity* (Cambridge, MA: Harvard University Press).

Le Poidevin, R. (2004a) “A puzzle concerning time perception” *Synthese*, 142: 109-142.

Le Poidevin, R. (2004b) “The Experience and Perception of Time” in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*.

Le Poidevin, R. (2007) *The Images of Time: An Essay on Temporal Representation* (Oxford: Oxford University Press).

Levine, J. (Unpublished Manuscript) “Demonstrative Thought.”

Lewis, D. (1971) “Analog and Digital” *Noûs*, 5: 321-328.

Libet, B. (2004) *Mind Time: The Temporal Factor in Consciousness* (Cambridge, MA: Harvard University Press).

Ludlow, P. (1999) *Semantics, Tense and Time* (Cambridge, MA: MIT Press).

Mach, E. (1959) *The Analysis of Sensations* (New York, NY: Dover Publications).

Malapani, C. and Fairhurst, S. (2002) “Scalar timing in animals and humans” *Learning and Motivation,* 33: 156– 176.

Matell, M. S. and Meck, W. H (2004) “Cortico-striatal circuits and interval timing: Coincidence-detection of oscillatory processes” *Cognitive Brain Research*, 21: 139-170.

Matthews, R. J. (1994) “The Measure of Mind” *Mind*, 103: 131-146.

Matthews, R. J. (2007) *The Measure of Mind: Propositional Attitudes and Their Attribution* (New York, NY: Oxford University Press).

McCall, S. (1994) *A Model of the Universe: Space-time, Probability, and Decision* (New York, NY: Oxford Clarendon Press).

McGinn, C. (1989) *Mental Content* (Oxford, UK: Blackwell).

McKinnon, N. (2003) "Presentism and Consciousness" *Australasian Journal of Philosophy*, 81(3): 305-323.

Meck, W. H. (2003) "Introduction: The Persistence of Time" in W. H. Meck (ed), *Functional and Neural Mechanisms of Interval Timing (Methods and New Frontiers in Neuroscience)* (Boca Raton, FL: CRC Press).

Meck, W. H. and Malapani, C., (2004) "Introduction to Special Issue of the 'Neuroimaging of Interval Timing'" *Cognitive Brain Research* 21: 133-137.

Mellor, D. H. (1981) *Real Time* (Cambridge, UK: Cambridge University Press).

Mellor, D. H. (1998) *Real Time II* (New York, NY: Routledge).

Michener. G. R., (1979) "The Circannual Cycle of Richardson's Ground Squirrels in Southern Alberta" *Journal of Mammalogy*, 60(4): 760-768.

Millar, A. (2003) "A Suite of Photoreceptors Entrains the Plant Circadian Clock" *Journal of Biological Rhythms*, 18(3): 217-226.

Millikan, R. (1984*) Language, Thought, and Other Biological Categories* (Cambridge, MA: MIT Press).

Millikan, R. (1993) "On mentalese orthography" in Bo Dahlbom (ed.) *Dennett and his Critics* (Oxford Blackwell: 97-123).

Moore, C. (1990) "Unpredictability and undecidability in dynamical systems" *Physical Review Letters*, 64: 2354-2357.

Moore, C. (1996) "Recursion theory on the reals and continuous-time computation" *Theoretical Computer Science*, 162: 23-44.

Moyer, R. S. and Landauer, T. K. (1967) "Time required for judgments of numerical inequality" *Nature,* 215: 1519–1520.

Mozersky, J. (2006) "A Tenseless Account of the Presence of Experience" *Philosophical Studies*, 129: 441-476.

Mycka J. and Costa, J. F. (2007) "A new conceptual framework for analog computation" *Theoretical Computer Science*, 347: 277-290.

Nida-Rümelin, M. (1996) "What Mary couldn't know" in Thomas Metzinger (ed.) *Phenomenal Consciousness* (Schoenigh, Paderborn).

Nida-Rümelin, M. (1998) “On Belief About Experiences: An Epistemological Distinction Applied to the Knowledge Argument” *Philosophy and Phenomenological Research*, 58 (1): 51-73.

Nida-Rümelin, M. (2002) “Qualia: The Knowledge Argument” in E. N. Zalta (ed.) *The Stanford Encyclopedia of Philosophy*.

Nichols, S. and Knobe, J. (2007) “Moral Responsibility and Determinism: The Cognitive Science of Folk Intuitions” *Nous*, 14(4): 663-685.

O’Reilly, R. C. (2006) “Biologically Based Computational Models of High-Level Cognition” *Science*, 314: 91.

Panda, S. and Hogenesch, J. (1998) “It’s All in the Timing: Many Clocks, Many Outputs” *Journal of Biological Rhythms*, 19(5): 374-387.

Peacocke, C. (1994) “Content, Computation and Externalism” *Mind and Language*, 9(3): 303-335.

Penrose, R. (1996) *Shadows of the Mind: A Search for the Missing Science of Consciousness* (New York, NY: Oxford University Press).

Perry, J. (1979) “The Problem of the Essential Indexical” *Nous*, 13: 3-20.

Pöppel, E. (1988) *Mindworks: Time and Conscious Experience* (New York, NY: Harcourt Brace Jovanovich).

Prior, A. N. (1959) “Thank Goodness, That's Over” *Philosophy*, 34: 12-17.

Prior, A. N. (2003) *Papers on Time and Tense* (Oxford: Oxford University Press).

Pylyshyn, Z. W. (2007) *Things and Places: How the Mind Connects with the World* (Cambridge: MA: MIT Press).

Reichenbach, H. (1947) *Elements of Symbolic Logic* (New York, NY: Macmillan).

Reichenbach, H. (1958) *The Philosophy of Space and Time* (New York, NY: Dover).

Renner, M. (1960) “Contribution of the honey bee to the study of time sense and astronomical orientation” *Cold Spring Harbor Symposium on Quantitative Biology*, 25: 361-367.

Russell, B. (1913) “On the Experience of Time” in B. Russell, E. R. Eames (eds.) *The Collected Papers of Bertrand Russell: The 1913 Manuscript*, Vol. 7 (Routledge, 1988).

Russell, B. (1937) *The Principles of Mathematics* (New York, NY: Norton).

Scholl, B. (2007) “Object Persistence in Philosophy and Psychology” *Mind & Language*, 22(5): 563-591.

Smart, J. J. C. (1949) “The River of Time” *Mind*, 58: 483-494.

Smart, J. J. C. (1963) *Philosophy and Scientific Realism* (London, UK: Routledge).

Smart, J. J. C. (1980) “Time and Becoming” in Peter van Inwagen (ed.), *Time and Cause* (Dordrecht, Holland: D. Reidel).

Smart, J. J. C. (2006) “Metaphysical Illusions” *Australasian Journal of Philosophy*, 84(2): 167-175.

Spence, C. and Squire, S. (2003) “Multisensory Integration: Maintaining the Perception of Synchrony” *Current Biology*, 13: 519-521.

Stalnaker, R. C. (2008) *Our Knowledge of the Internal World* (New York, NY: Oxford University Press).

Stetson, C., Cui, X., Montague, P. R. and Eagleman, D. M. (2006) “Motor-Sensory Recalibration Leads to an Illusory Reversal of Action and Sensation” *Neuron*, 51: 651-659.

Stevens, S. S. (1959) “Measurement, Psychophysics and Utility” in C. W. Churchman and P. Ratoosh (eds), *Measurement: Definitions and Theories* (New York, NY: John Wiley & Sons, pp. 18-63).

Stone, J. V., Hunkin, N. M., Porrill, J., Wood, R., Keeler, V., Beanland, M., Port, M. and Porter, N. R. (2001) “When is Now? Perception of Simultaneity” *Proceedings of the Royal Society (B)*, 268: 31-38.

Strogatz, S. (2003) *Sync: The Emerging Science of Spontaneous Order* (New York, NY: Hyperion).

Suppes, P. and Zinnes, J. (1967) “Basic Measurement Theory” in R. D. Luce (ed.), *Handbook of Mathematical Psychology* (New York, NY: Wiley and Sons).

Tooley, M. (1997) *Time, Tense and Causation* (Oxford, UK: Oxford University Press).

van Fraassen, B. (1989) *Laws and Symmetry* (Oxford, UK: Clarendon Press).

Vander Wall, S. B. (1990) *Food hoarding in animals* (Chicago, IL: University of Chicago Press).

Velmans, M. (1991) “Is human information processing conscious?” *Behavioral and Brain Sciences*, 14(4): 651-668.

Wegner, D. M. (2002) *The Illusion of Conscious Will* (Cambridge, MA: MIT Press).

Wehner, R. and Müller, R., (1993) “How Do Ants Acquire Their Celestial Ephemeris Function?” *Naturwissenshaften* 80: 331-333.

Welch, R. B., DuttonHurt, L. D. and Warren, D. H. (1986) “Contributions of Audition and Vision to Temporal Rate Perception” *Perception and Psychophysics*, 39: 294–300.

Xu, F., & Spelke, E.S. (2000) “Large number discrimination in 6-month-old infants” *Cognition,* 74: 1–11.

Zahavi, D. (2005) *Subjectivity and Selfhood: Investigating the First-Person Perspective* (Cambridge, MA: MIT Press).

Zimmerman, D. (1998) “Temporary Intrinsics and Presentism” in van Inwagen, P. and Zimmerman, D. (eds.) *Metaphysics: The Big Questions* (Oxford, UK: Basil Blackwell, pp. 206-219).

Zimmerman, D. (2002) “God Inside Time and Before Creation” in G. E. Ganssle and D. M. Woodruff (eds.), *God and Time: Essays on the Divine Nature* (New York, NY: Oxford University Press pp. 75-94).

Zimmerman, D. (2005) “The A-theory of Time, the B-theory of Time, and ‘Taking Tense Seriously’” *Dialectica*, 59(4): 401-457.

Zimmerman, D. (2008) “The Privileged Present: Defending an ‘A-Theory’ of Time” in Sider, T., Hawthorne, J. and Zimmerman, D. (eds.) *Contemporary Debates in Metaphysics* (Malden, MA: Blackwell pp. 211-225).

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2007 (with Balci F.) "Compositionality in Language and Arithmetic" *Journal of Theoretical and Philosophical Psychology*, 27(1): 53-72.

2008 "Moral Innatism and Legal Theory" *Problema*, 2: 407-430.

2008 (with Haladjian, H. H. and Pylyshyn, Z. W.) "Segregating targets and nontargets in depth eliminates inhibition of nontargets in Multiple Object Tracking" *Visual Cognition*, 16(1): 107-110.