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MAKING SENSE OF SUBJECTIVE TIME

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Introduction: subjective time

In what sense, if any, is there such a thing as "subjective time", as distinct from the objective temporal relations between physical events? With most perceptible features, like color, taste, smell, shape, distance, lighting, etc., it is widely accepted that experience is not simply a direct confrontation with an objective feature; in particular, we need a distinction between the objective feature, and the *way we experience it*. One way of understanding the question about subjective time is this: is there a "way we experience" duration, and if so, how should it be characterized? This chapter is an overview of some of the problems we encounter trying to answer this question. The overall message is that although there are strong arguments for believing in subjective features of duration experience in a fairly strong sense, there are pitfalls to avoid in thinking about them, and serious problems understanding how they are individuated.

A classic entry point for thinking about the idea of a "subjective aspect" of experience, is through the notion of *inter-subjective phenomenal variation*, of which we can distinguish weak and strong varieties. We have weak inter-subjective variation in experience of a feature if it is possible for different subjects to have different experiences of that feature of an object or event in a given context. Weak variation is pretty uncontroversial, because most philosophers and psychologists accept the possibility of *perceptual illusion*. So in the case of duration, we might both hear the same sound, but have different experiences of its duration, because one of us is suffering from a perceptual illusion of its duration. Such duration illusions are widely documented in the empirical literature (see Eagleman (2008) and Grondin (2010) for reviews). This at least forces us to distinguish between objective duration and *apparent* objective duration, and gives us one important sense in which there is "subjective time".

More controversial is the possibility of *strong inter-subjective variation*: variation between subjects in the experience of a stimulus feature, despite the normal functioning of the subjects' perceptual systems, and despite the subjects' experiences *not* being illusory. For example, some have argued that strong variation in color experience is possible[1]: your color qualia might be inverted (or otherwise variant) with respect to mine, despite both our visual systems functioning normally, delivering us accurate information about the surfaces of objects.

Such variation is at least prima facie conceivable for duration experience. For example, it's conceivable that other well-functioning creatures could be living in an experiential world that is

analogous to a time-lapse video or a slow-motion replay. Consider the hummingbird: perhaps their experience of a 500 msc flash is comparable to a human's experience of a 2 second flash, and, more generally, they experience changes as occurring more slowly than we do by some determinate factor. But does this really make sense? What would it consist in, and what would show that it is possible?

The image of "slow-motion" experience suggests a very specific picture of what strong variation in duration experience would consist in. It suggests that there is a parameter, something like "rate of flow", that measures how fast events pass through the stream of consciousness for a given subject, which could vary between us and, say, a hummingbird. One main goal of this chapter is to explain why we should be wary of this picture. It embodies a number of substantive assumptions about duration experience which I want to tease out, and which are not necessarily required for thinking that duration experience has strongly variable subjective features. But first, a little more clarificatory setup is in order.

It's important to note how varied duration experience is: in particular, we experience duration at different temporal scales, and in different sensory modalities.[2] At small temporal scales (less than about 1–2 seconds), our experience of duration is analogous to our perceptual experience of visual features like shape, color, lighting, or features of sounds like pitch and timbre, in that it feels like an immediate perceptual confrontation with a feature of a currently perceived event. Beyond this scale, duration experience is in an interesting category that straddles memory and perception. Consider the example of reflecting on how long you have been reading this chapter. This involves a memory of an event – your starting to read the chapter. But it is also quasi-perceptual, in the sense that it involves a perceptual tracking mechanism (a mental timing device) that delivers awareness of information *about the present*: namely, how present events are temporally related to a past event.

For each of these wide-ranging forms of duration experience, I'll assume that there is "something it's like" to have the experience, so we can talk about the features of experience that constitute this "duration phenomenology", which I'll call "experiential duration properties", or ED properties. Different accounts of the metaphysics of such phenomenal properties (and there's a whole zoo of these) can be applied here. In particular, they might consist of relations of acquaintance or representation to objective duration properties,[3] or they might have a more contingent relationship to external stimulus features, being more like internal subjective signs of external temporal properties. These distinctions will become relevant later in the chapter. What will now be important is the (more metaphysically neutral) claim that there exists a space (or spaces) of such ED properties, a *duration quality space*, structured by *similarity relations*, the kind of similarity relations we have (perhaps highly fallible) access to, when we make temporal similarity judgments based on experience.

What makes it at least *conceivable* that there is strong inter-subjective variation for duration is that we can imagine subjects having dispositions to have experience with systematically different ED properties in response to the same stimuli: that is, they have different *psychometric mappings* from physical durations into a duration quality space. (A psychometric mapping is a function telling us what the probable psychological or behavioral response is to a certain stimulus; of course, because perception is noisy, there will typically be variation in the response a particular stimulus causes; and the mapping may only be valid in a limited range of contexts.) For example, the hummingbird's psychometric mapping might map an objective duration onto a different duration experience from the human mapping.

Actually, as mentioned, what we tend to imagine here is something much more specific, something more like *time flowing at different rates for different subjects*. It is as if the stream of consciousness is a liquid that can flow at different speeds in different subjects at different times.

I'll now turn to the task of articulating the assumptions suggested by such a picture. I'll argue that contemplating the ways in which they might fail reveals a wider range of ways in which there could be strong inter-subjective variation in duration experience than mere variation in "rate of flow" (if that is even a well-defined quantity).

Rates of flow

What would it take for differences in dispositions to have duration experience to be capturable be a single, variable, *quantity*, the "rate of flow"? First, it requires that all the duration experiences of different individuals, and also of a single individual, be drawn from a single quality space. Call this *comparability*. If comparability fails, then some duration experiences across or even within individuals are in *alien* quality spaces, much as human color experience and bat echolocation experience may be alien. Comparability is non-obvious; for example, different creatures might measure time using very different timing mechanisms, and code it in different ways on totally different hardware. If there are such differences, is it clear that our experiences are comparable with theirs? (Compare how, if we found such differences in the detection and coding of surface reflectance features, we wouldn't assume comparable *color* experience.) Even *intra*-subjective comparability is not totally obvious; for example, maybe visual and auditory duration form different spaces, or duration experiences at different scales form different spaces.

Notice that if comparability fails, then this gives us a (less obvious) way in which strong variation could obtain. We just need to assume that if a creature's temporal experiences form an alien quality space, this doesn't mean that their experience is illusory or that they aren't optimally functioning. But that seems reasonable, since the mere fact that they have alien experiences doesn't set up any relevant asymmetry between us and them.

Even if we assume comparability, we may not have *unitarity*. This is the assumption that there is a single psychometric function modeling a single subject's experiences across modalities, at different scales and domains. Strict unitarity is actually quite unrealistic – as any psychophysicist will tell you. The issue is controversial, but much research suggests that human cognitive timing doesn't use a single internal clock, but rather a variety of devices in different scales and domains with at least slightly different psychometric characteristics (Buhusi and Meck 2005; Johnston *et al*. 2006). In terms of the metaphor of "flow", it is more like there are many inter-connected streams running noisily and unevenly at approximately the same speed, rather than one single smooth stream; therefore there can be no single precise value for the "rate of flow" (let's be careful though: the stream metaphor is inept in certain other ways I'll bring out below).

Note that we are very familiar with experiences where unitarity fails (although they may involve illusions). For example, consider "time flying when you're having fun". This is a case where mechanisms keeping track of the passage of time at the level of minutes/hours function differently, changing the psychometric relation for temporal experience at the minute/hour scale; nonetheless the psychometric function for *millisecond* timing typically remains normal: it is not as if having fun makes the world look to run in "fast-motion".

Assuming comparability and unitarity, we have a single psychometric function from objective durations to subjective durations modeling a subject's dispositions to have duration experience, and different subjects' experiential dispositions will be relatable as a transformation of this function. What form does this function take? To answer this question, we first need to know what kind of structure the quality space of ED properties has. Duration experience allows individuals to discriminate *metric* relations between durations, such as "d_1 is equally similar to d_2 and d_3", not just order relations on durations (d_1 is greater than d_2 and smaller than d_3). This gives us a reason for thinking that duration quality space has a *metric structure*. Duration quality space is, plausibly,

also *one-dimensional* – there is only one dimension of similarity on which we compare durations (unlike, say colors or spatial locations). Thus, a duration quality space will have the same 1-d metric structure as the space of durations itself (or an initial segment of that space, as some durations are too long to perceive).

What shape does the psychometric function from objective duration into this space take? The idea of "rate of temporal flow" as a quantity measurable by a single number suggests a linear function that is origin-crossing, i.e., it has the form $S = cD$, where S is a variable for ED properties, D is objective duration, and c is the rate of flow, corresponding to the gradient or steepness of the function. I'll call this assumption *linearity*.

Even if human temporal experience is actually (approximately) linear, the existence of *non*-linear temporal experience either in humans or other organisms is pretty clearly possible, and wouldn't even be particularly strange. Non-linear psychometric functions are pretty much the norm when it comes to the experience of other stimulus features like loudness, brightness, etc. And we can at least conceive of non-linear functions for duration experience. For example, a hypothetical creature might have timers that represent *log* duration, and which realize temporal experience in such a way that it has a log psychometric function (indeed, psychologists take seriously the idea that some of our timers might be non-linear (Crystal 2001)), including the idea that they use log timing (Gibbon and Church 1981). It is hard to be more specific about what exactly the functional/physical conditions are under which experience would involve non-linear timing, such as log timing (in fact, I think the difficulties here run deep (see Lee 2016)). Nonetheless, in so far as we think that our observations of the functional/physical structure of perceptual processing in other cases (loudness, brightness, heaviness, color, etc.), give us evidence for believing they are governed by a non-linear psychometric function, it is hard to see why we couldn't have similar reason for thinking that duration experience is non-linear.

Assuming that's right, would there be any reason for thinking that such a subject's (non-linear) experiential responses would be illusory or that they would not be optimally functioning? Take the case of *log* coding of duration. Would this entail sub-optimal functioning? In other cases, the rationale for such coding is that it allows us to represent differences in a quantity over a wide range of scales using a single representational parameter. As it happens, we have evolved separate representational systems for time at different scales (from milliseconds to years), and so we probably don't need to use the trick of log coding. But there is no reason why a less sophisticated cognitive system couldn't employ this trick for duration, or, indeed, why we couldn't. So optimal functioning is clearly compatible with log timing. Would it involve some kind of massive illusion? The trouble with saying this is that it commits you to saying human experience is massively illusory all over the place: most perceptual representations involve non-linear coding of stimulus features, but we still think of them as providing accurate information, and therefore as "veridical" in the most important sense (this issue clearly deserves much more extensive discussion).

In sum, it seems to be possible for linearity to fail, so that temporal experiential dispositions are given by a more complex psychometric function than the linear function presupposed by the "rate of flow" picture. Moreover, if it's true that such non-linear experiences need not involve illusion or non-optimal functioning, this provides us with another non-obvious way for strong variation to be realized.

Let's call the combination of comparability, unitarity, and linearity "the simple flow view"; it entails that "rate of flow" is a well-defined inter-personal quantity. A further important clarification: on the simple flow view, "rate of flow" is just a number describing our *dispositions* to experience external stimuli; it need not be understood as measuring something more *intrinsic*, like *how much experience* flows by each second. Thus, even if we accept the view, there is *still*

something potentially misleading about the "flowing water" analogy. Whether there is some such intrinsic measure of "how much" experience we have over time is a further interesting question, which is important for certain practical issues about experience (e.g., more pain is worse than less pain) (see Lee (draft manuscript 2013) for more detailed discussion).

Having noted this, let's return to our discussion of strong variation. We have seen in this section that one way of arguing for strong variation is by challenging elements of the simple flow view: comparability, unitarity, and linearity. But we can also argue for strong variation in a way that is compatible with the simple flow view – this is the topic of the next section.

The possibility of strong variation on the simple flow view

Assuming the simple flow view, the kind of "strong phenomenal variation" we are interested in can be described as follows: can there be a possible individual whose "rate of temporal flow" is uniformly faster or slower than ours, in the sense that the psychometric function describing their disposition to have duration experiences is a linear transformation of ours, or more specifically, it is the same function multiplied by a constant factor?

What physical/functional differences would there be between us and such an individual? Because their experiences differ from ours only in that their "absolute value" is multiplied by a constant (unlike an individual whose psychometric function is a non-linear transformation of ours), you might think that they will be disposed to make the same temporal judgments as us. For example, if a two-second stimulus seems to us equally similar to a one-second and three-second stimulus, this will be true for them too, even if all the stimuli appear to them to last, say, twice as long (in a phenomenal sense). However, characteristic functional differences (including differences in judgments) may nonetheless exist, for example, those having to do with differences in *range of sensitivity* (which temporal stimuli they can perceive at all), and the *variance* of their responses to a particular temporal stimulus (i.e., how *reliably* they perceive durations, rates of change within some range). For example, a hummingbird might be able to visually perceive changes that are too rapid for human vision, and be more reliable at perceiving fine-grained temporal detail.

To clarify, I think it is helpful to see that there are possible cases where conditions obtain that are plausibly *sufficient* (but not necessary) for a difference in "rate of flow". In particular, we can consider a case where an individual has a cognitive system almost exactly like a normal human's, except that their neural processing operates faster or slower than ours by some constant factor: the signaling speed between neurons and the firing rates of neurons, and any other processes relevant for cognition all happen at a uniformly faster or slower rate.[4]

For example, consider an individual whose processing speeds are five times faster than ours. Then the temporal resolution and range of sensitivity of their cognitive timers would all be shifted by a factor of five. More generally, their response to a stimulus with certain temporal features would be isomorphic to our response to a version of the stimulus stretched out in time by factor of five. For example, if we enjoy listening to music with a tempo range of 70 bpm to 200 bpm, they would enjoy listening to music with a tempo range between 350 bpm and 1000 bpm. If we find speech to be intelligible when the syllables are pronounced at a certain rate, they would find it intelligible at a rate scaled from ours by a factor of five. And so on.

I think such an exact functional correspondence between our reactions to stimuli (including all internal processing) and their reactions to rescaled versions of the same stimuli, makes it plausible that there is also an experiential correspondence here: that is, their experiential psychometric function for duration is simply a rescaled version of ours. More specifically, the only difference between our neuro-cognitive reaction to a *n* second stimulus and their reaction to a rescaled

n/5 second version of the same stimulus is the period of time over which the neuro-cognitive response unfolds: their response is a temporally rescaled version of our response. It is only if the temporal scale of the response is experientially relevant that our experiences of these counterpart stimuli could be different. In other words, not only is there an exact correspondence in the causal structure of neural events occurring in response to the counterpart stimuli, every other physical aspect of the response is the same, except for temporal scale. This is why there is a very strong argument for saying that there is experiential sameness here (i.e., our experiences are exactly like those they would have of a temporally rescaled stimulus).

I would give the following supplementary argument to back this up. We argued above that a subject with a non-linear psychometric function for time is surely possible, and moreover we can imagine a functional organization that we might take as evidence for such experiential dispositions. But if there are physical/functional differences between us and another subject that are sufficient for our psychometric functions to be related by a *non*-linear transformation, it would be surprising if there were not also physical/functional differences that are sufficient for our functions to be related by a simpler *linear* transformation; and the differences described seem like a very plausible candidate for this.

What we have here is an argument that certain conditions are sufficient for an individual's duration psychometric function to be a rescaled version of ours. Let's note a couple of things about this. First, if linearity and unitarity fail to be true of us, this doesn't really spoil the argument. If in fact our experiential dispositions can only be accurately captured with a bunch of different functions for different ranges, domains, sensory modalities, contexts, etc., then that will be true of our rescaled duplicate. And if these functions are non-linear, that will be true of our duplicate. So what we really have here is an argument for a sufficient condition for a relationship between subjects of *psychometric rescaling*.

Finally, let us note that given the evident symmetry between us and such a "rescaled" subject, it would be very implausible to claim that their perceptual system is functioning any better or worse than ours, or that it is producing mental representations that are any more or less accurate than ours. So if such a subject could exist, they are clearly an instance of strong variability in duration phenomenology.

More could be said about these arguments in favor of strong variability, but I now want to switch tacks, looking at some problems that arise when we try to make sense of what such properties consist in. As we will see, there are serious difficulties giving a clear account of the conditions of individuation for these subjective properties; so although there are good arguments that they exist, their existence is not straightforwardly philosophically unproblematic.

Problems individuating experiential duration properties

Let's now assume that ED properties are individuated in a way that allows for strong interpersonal variation. We gave a sufficient condition for psychometric rescaling in terms of processing speeds. However, that does not tell us what the necessary and sufficient conditions are for a subject to have a certain ED property. For example, what are the exact conditions under which the kind of duration experience you typically have in response to a 2 msc auditory stimulus occurs? There are a number of serious problems that arise when we try to answer this question.

One approach here that will tempt many is a representational (or more generally "relational") one. The idea is that the character of a subject's experience is constituted by the properties of the stimulus that it represents[5] (or to which it enables some other intentional relation like "acquaintance"[6]). If such a general approach to individuating phenomenal properties is correct,

then we can distinguish ED properties from others in terms of which property or properties they represent.

Suppose we want a representational account that allows for strong inter-subjective variation in duration phenomenology. Then duration experience can't simply consist in experiential representation of objective duration. If it did, then phenomenally different experiences had by different subjects in response to the same stimulus duration would represent different objective durations, and therefore could not all be veridical. Rather, such a representationist is likely to appeal to the representation of *relative* duration. Compare size perception: an object might in some sense look larger to a small rodent than it does to a fully grown adult; nonetheless they might both be veridically perceiving its size. The obvious way to resolve the superficial contradiction here is to say that they perceive its size only relative to *their* size (or some more specific aspect of it like eye-height). Similarly, a representationist might say that stimulus duration is represented by an ED property only relative to a bodily temporal parameter, such as the rate of some internal process in the brain involved in time perception. If the relevant process is running faster in me than in you, then having veridical experiences of the same duration will require it to look longer to me.[7]

This might seem like an attractive approach, giving us a neat account of the metaphysics of ED properties that allow for strong variation. But it raises two difficult questions. First, how exactly should we understand the sense in which objective duration is *relativized* to the rate of an internal process? Second, what is the relevant internal process?

On the first question, I want to distinguish two different versions of the "relative duration view" and argue that they are both problematic, to the detriment of a representational approach.

On one version, there is an internal process that provides a *particular* duration relative to which everything is measured, such as the duration of one click of an internal clock. This duration provides a *unit*, so there will be some specific number of units associated with each ED property, and a shift to a different "rate of temporal flow" will correspond to a change in units. On this view, it is literally the case that each time you experience a duration, there is a certain number of "mental seconds" that it is experienced as having.

This view is quite implausible, however. It is phenomenologically implausible, as there is nothing in experience indicating that one duration has a special privileged status, or that there is a number associated with each duration experience. Peacocke (1992: 68–69) is surely right in holding that our experiences of temporal and spatial quantities are "unit-free". But perhaps more significantly, there is no reason to think of the states of internal timers that are used to track time and which underpin these experiences as using a unit-relative representational system. For example, one kind of timer that might be used by cognitive systems is an accumulator. To give an example, imagine a tank of water filling up at a uniform rate in response to the onset of a stimulus, and stopping at the termination of the stimulus. The height of water in the tank represents the duration of the stimulus. There are no units in which time is measured here. It is represented by a physical quantity – height of water – that does not itself intrinsically involve a unit: we could measure it in cm, meters, or whatever we like; moreover, there is no segmentation between different water heights indicating temporal units (e.g., there are no lines notched up the side of the tank). I believe that in the case of more realistic representational systems (such ramping or decaying neural firing rates representing the passage of time), there will similarly be a physical quantity (e.g., firing rate) representing duration that doesn't inherently involve a unit of representation (although the point certainly deserves longer discussion to account for different kinds of timing mechanisms and representational systems[8]).

In response, we might try to find an alternate way of understanding relativization that doesn't require units. This can be done. Imagine again using a tank filling with water to measure

duration. Everything is relative to the rate of filling of the tank. If we sped this up, then different durations would be represented by different heights (or the device would start misrepresenting). The amount of "tank time" indicated by water height is *proportional* to filling speed, so the "relative" temporal quantity represented can be thought of as [duration of stimulus * tank filling speed]. Since both components of this are unit-free physical quantities, the overall quantity is unit-free. So in this way, we can relativize our representation of duration to tank filling speed (or, more realistically, the rate of some internal neural process) without understanding the situation as involving units of measure.

This way of understanding relativization has the advantage of being unit-free, but unfortunately it has a serious problem too. It boils down to this: the relative quantity "duration of stimulus * tank filling speed" is really the same quantity as "height of water in the tank" (e.g., imagine this relative to units like seconds and meters: seconds * (meters/second) = meters). Or to give a more realistic example, the quantity "duration of stimulus * decay rate of neural decay timer" is really the same as "firing rate of neural timer" (here I'm imagining a timer that uses a firing rate inversely proportional to elapsed duration to measure duration). In trying to relativize the represented objective temporal quantity to the rate of an internal process, we end up with a view on which the system is representing its own internal state rather than the state of the stimulus! Perhaps a little more charitably, we could think of the proposal as saying that the system is representing the stimulus's disposition to produce a certain internal state in the system (water height/firing rate), one that correlates with a certain objective duration. Still, this is an odd way of looking at it: what is really going on is that the system is going into a certain internal state whose role it is to represent the objective duration of the stimulus. It's true that had the normal operating speed of the timer been different, it would have represented a different objective duration. In that way, the water height/neural firing rate representation is "relative to the speed of the timer". Still, attempting to construe this as the representation of a relative quantity tends to lead to this odd result.

Of course, anti-representationists (such as myself) will take this as grist for their mill; representationists will have to find a way to circumvent or deflate these problems (one option is to deny that strong variation is possible, and thus undercut the motivation for relativization in the first place. But of course, that will be unattractive without a response to the considerations of rates of flow and the possibility of strong variation on the simple flow view discussed earlier).[9] Here is not the place to try to adjudicate the big theoretical question of whether representationism in general is true, however. I rest content by pointing out that clarifying in a plausible way what "relativization" is, is problematic.

Another problem with relativization is identifying the relevant internal process whose rate is being used to measure time. There are two versions of this problem. On the representational view currently under discussion, we want to identify a represen*ted* internal quantity. But even if we reject the representational view, we may well think that there is some set of internal states that are necessary and sufficient for different kinds of duration experience, or some internal process whose rate determines the "rate of flow" of a subject's experience, and want to know what these physical quantities or processes are. There are very similar problems that arise identifying the "individuating quantity" in either case, so I will discuss them in the same breath.

I want to distinguish three closely related problems that arise with individuation: the *localization problem*, the *abstraction problem*, and the *mapping problem* (see Prosser 2016, chapter 4, for a related discussion). It should be noted at the outset that similar problems are likely to arise for the individuation of *any* phenomenal properties (see, in particular, Papineau 1993: §§4.8–4.10, 2002, chapter 7), although I think the issues play out in a particularly interesting way in this case.

The localization problem is this: even if we identify relatively local neural populations whose features code the duration properties represented in experience, it is implausible that the phenomenology of duration is determined solely by such localized properties; context matters too. For example, replacing a neural timer involved in auditory perception with a faster one that has a higher resolution (e.g., more "ticks" per second), and uses the same states to code different durations (e.g., the representation caused by ten ticks now denotes a different duration), won't necessarily "speed up time" or otherwise change the experience the subject has of a certain objective duration, because the timer may be integrated with surrounding neural processing in a way that is exactly the same as in the old system. Plausibly, these contextual factors are phenomenally relevant too.[10] But if duration phenomenology is partly grounded in such contextual features of local timers, what exactly are they? That's the localization problem.

A good way to see the abstraction problem is through the lens of comparability: the assumption that all duration experiences are drawn from a single quality space. If comparability is true, then the individuating quantity will have to be a physical quantity that is present whenever there are experiences of duration, in *absolutely any context*: it will be there for every kind of human temporal experience, as well as in temporal experiences of every possible subject, including non-human cognitive systems. This immediately rules out a lot of natural candidates: for example, you might picture time being measured against the rate of an internal clock. But if ED properties are individuated by a specific kind of clock mechanism, then such a mechanism will have to be in place for them to be instantiated. That means that if non-human creatures use a different mechanism to keep track of time, they can't have temporal experiences like ours – we will have a failure of comparability. This leads to the abstraction problem: if ED properties can be shared by a wide variety of creatures using different systems to track and code time, then they must be individuated sufficiently abstractly to allow for this.

The mapping problem is a way of illustrating through example the myriad problems with individuation (in a sense then, it is not a separate problem, but a way of dramatizing these problems). Suppose we encounter a creature that has conscious experience, but whose temporal processing is different from ours in a highly *non*-systematic way. Perhaps they are able to perceptually experience a broader range of durations than us, and their perceptual systems operate at a broader range of speeds and temporal resolutions. For example, suppose they have something like vision and audition; but their visual processing is adapted to pick up changes at a longer temporal scale than ours, and in general operates more slowly; but their auditory processing is significantly faster and has a higher temporal resolution than ours, and is adapted to pick up changes at finer temporal grain. Moreover, the temporal coding schemes and detection mechanisms these systems use are at least somewhat different from ours. The question is: how do their experiences map onto ours? For example, how do we figure out what it is like for them to experience a 500 msc stimulus under normal conditions? Which of our experiences is this phenomenally comparable to?

In the case where an organism has processing exactly like ours but uniformly faster or slower, there was a principled reason why one mapping could be taken to be correct. But in a case like this – where their processing is in one way faster, and in another way slower, and there are other differences too – it is hard to see how there could be one mapping that is more natural than others. The physical state they go into when they experience, say, a 500 msc stimulus is similar to each of a *range* of states we go into when experiencing a *range* of different stimulus durations, but not most similar to any one of those states. But *all we have to go on in figuring out phenomenal similarity here is similarity in physical/functional states*: so, viewed from an external perspective, nothing can tell us what the right mapping is.

What to make of this? There are various responses (I can't attempt to adjudicate between them here). First, we could conclude that it is simply *indeterminate* how to map their experiences onto ours (Papineau 1993, 2002). Second, we could hold that there is a single mapping that preserves phenomenal character, it is just that it is inscrutable from a third-person perspective, and would seem arbitrary if we knew what it was. This option can be glossed in a more deflationary way, on which it really *is* arbitrary what the mapping is (this is similar to the first response), or in an inflationary way, on which the mapping does correspond to a deep "joint in nature", albeit one that is inscrutable from an objective perspective (see Lee forthcoming). Third, we could conclude that comparability fails, holding that their temporal experiences form an alien quality space, despite also being experiences *of* duration (the fact that this option is considerably less attractive for time than for "secondary" qualities like color is an important reason why this case is independently interesting). Finally, (and more obscurely), we might be tempted by the "Frege-Schlick" view, on which one cannot meaningfully compare phenomenology across organisms (Stalnaker 1999; Shoemaker 2006), and so the mapping problem is based on a false presupposition. All of these options (which are unattractively counterintuitive in different ways) deserve extensive further discussion.

Finally, it is worth noting that there is a related *intra*-personal mapping puzzle. In particular, the kinds of physical/functional differences between individuals that lead to inter-personal phenomenal mapping puzzles might in principle also exist in different sensory modalities within a single individual. Specifically, if temporal processing is modality-specific, then quite different physical/functional states might underlie temporal experience in different modalities. For example, it is well known that human vision and audition have very different temporal resolution (audition is finer-grained).[11] Considering the int*er*-subjective case, theorists have been tempted to conclude that an organism with higher temporal resolution perception than a human may be living in a "slow-motion" world (see e.g., Healy *et al*. 2013). But should such theorists therefore conclude that time passes at quite different rates in human audition and vision? More generally, is it an epistemic possibility that unitarity or comparability fail in a significant way across modalities within a single organism?

It might seem like the answer is "obviously not" – we can tell introspectively that auditory and visual temporal phenomenology are congruent: they involve very similar experiences of the same objective temporal phenomena. Therefore, there is no intra-subjective mapping problem here. Or to put it another way, if auditory duration and visual duration are massively different, then we are subject to massive systematic introspective illusion – but such illusions seem inconceivable (although see Lee (2016), for doubts about the significance of this intuition).

Things are not so simple, however. One might worry that for *any* proposal for what the individuating quantity is, we can set up a case where it is multiply realized in different sensory modalities, in such a way that they involve quite different psychometric functions for duration experience (we have a large failure of unitarity). Nonetheless, if the modalities are wired together so that the subject can make accurate inter-modal comparisons of (objective) duration, they wouldn't notice any inter-modal discrepancy in phenomenology (here I'm assuming that introspection of phenomenology works through the redeployment of objective perceptual judgments). If we assume that systematic introspective illusions are always impossible, we can use this setup to rule out *any* candidate for the individuating property. We might start wondering if any satisfactory account can be given of what it is. I think this issue raises serious, possibly intractable, problems that deserve more extensive discussion (see Lee 2016).

To sum up: there are a number of serious problems we face attempting to individuate ED properties. First, if we think that they involve the representation of (or some mental relation to) *relative* duration properties, then we must say in what sense we have "relativization" here;

we saw that both unit-relative and unit-free answers to this question have problems. Second, if an internal neuro-functional quantity individuates duration experience (either because it is represented as the quantity against which external duration is measured, or because it directly constitutes duration phenomenology), then we want to know what it is: this is the individuation problem. This leads to the localization, abstraction and mapping problems just described. My goal here is not to solve the problems; I simply want to raise them as a way of highlighting how hard the individuation problem is.

Concluding remarks

We have seen that there are strong motivations for believing in the possibility of strong phenomenal variation for duration experience, some of which involve questioning the assumptions of a picture of temporal experience I precisified as "the simple flow view", on which experience has a well-defined "rate of flow". Nonetheless, there are some serious difficulties understanding how such variable phenomenal features are individuated. Future work in this area ought to address these problems, which will require confronting difficult questions (some of which I raised here) about the ways in which timing devices in the brain represent time, and how these representational states relate to the conscious experience of time. Our understanding of the underlying neuro-functional mechanisms here is still extremely rudimentary, and no doubt further developments on the empirical side will inform our philosophical accounts of subjective time. This is an area with much interesting philosophical work waiting to be accomplished.[12]

Notes

1 See Shoemaker (1982), Block (1990), Nida-Rümelin (1996).
2 For reviews see Buonomano and Karmarker (2002), Buhusi and Meck (2005), Grondin (2010), Merchant *et al*. (2013), and the papers in Merchant and De Lafuente (2014).
3 For the representational view, see, e.g., Dretske (1997), Tye (2000); for the acquaintance view, see, e.g., Campbell (2002). Phillips (2013) theorizes temporal awareness from an acquaintance perspective; Tye (2003) defends his representational view specifically for temporal awareness.
4 Prosser (2016, chapter 4) considers a similar example.
5 See, e.g., Dretske (1997), Tye (2000).
6 See, e.g., Campbell (2002).
7 Thompson (2010) discusses a version of the relativizing response for space, and Phillips (2013) defends a version of the view for duration experience.
8 For theoretical accounts of the representational properties of different timing systems, see Gallistel (1990), Montemayor (2012).
9 Another option is to consider relational properties other than relative duration, e.g., Prosser (2016, chapter 4) argues that duration experiences represent relational functional properties.
10 Although see discussion of the intra-subjective mapping problem for considerations that somewhat problematize this intuition.
11 This formulation is an oversimplification, because there is no such thing as "the" resolution of vision; rather different visual processes have different resolution (Holcombe 2009).
12 Thanks to Ian Phillips for comments on an earlier draft.

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