Time and experience

Rick Grush
UC San Diego Philosophy

1. Introduction

Nothing is more obvious than the fact that we are able to experience events in the world such a ball deflecting from the cross-bar of a goal. But what is the temporal relation between these two things, the event, and our experience of the event? One possibility is that the world progresses temporally through a sequence of instantaneous states – the striker's foot in contact with the ball, then the ball between the striker and the goal, then the ball in contact with the cross-bar, and so forth –, while the perceiver's experience is likewise a sequence of experience states, each one of which corresponds to, or is experience of, a corresponding state of the world – for example, a perception of the foot in contact with the ball, followed by a perception of the ball in the air, following by a perception of the ball in contact with the cross-bar. This way of understanding the relationship between experience and the world is very natural, and nearly universal. However, it rests on two assumptions that can be brought into question.

First, it assumes that at any time, the content of what is experienced is a temporally punctate state of the world. Second and relatedly, it assumes that the sequence of experience states temporally tracks the sequence of states of the world. The fact that we can perceive motion provides some reason to question the first assumption. Motion can only manifest over a temporal interval of non-punctate magnitude, so if we can *perceive* motion, then the temporal content of an experience cannot be limited to a temporally punctate instant. The existence of temporal illusions – cases where it seems as though A followed B even though in fact B followed A – provides some reason to question the second assumption. If the sequence of experience states just tracked the corresponding states of the world, then such illusions would not be possible.

In what follows, I will discuss both of these issues – the perception of motion and temporal illusions – in more detail. I will then outline an alternative way to understand the temporality of experience that denies both of the assumptions. That is, on this alternative proposal, the content of experience at any instant is not temporally punctate, but includes a temporal interval; and second, the details of what is experienced within this interval is not a mere passive reflection of the world's temporality, but is the result of active interpretation. This alternative picture I call the *trajectory estimation model*.

2. The perception of motion, and the specious present doctrine

It will be important for what follows to clearly distinguish two different ways in which time is involved in experience. First, experience is something that happens in time; or to put it another way, there are temporal features of *representings*. I might see the electrical discharge before I hear it, for example, and this temporal order is an order of my representational states. Second, experience is often experience *of* objective things that have their own temporal features; call this the temporal features of the *represented*. *One* way (but not the most interesting way, as we shall see) in which these can come apart is due to the fact our perception of events is causally mediated by various kinds of signal transmissions, and so, for example if Alice is a few hundred meters away and Bob is very close, I might hear Bob's yell before I hear Alice's yell (this is a temporal relation between my represent*ings*) even though Alice yelled before Bob (this is a temporal relation between the represent*ed* events).

Let's turn now to the following question: do you *perceive* the motion of the clock's second hand? To see what I mean, compare your perceptual experience of the second hand to your perceptual experience of the hour hand. The hour hand *looks* motionless; you would not be able to tell whether the clock was broken by just glancing at the hour hand. Of course you can determine that the hour hand is moving if you compare its location as you now perceive it to its location as you remember it from some time ago. So you can come to know that the hour hand is moving by means of an inference one of the premises of which is supplied by your current perceptual state, and another of which is supplied by your memory (or a prior perceptual state) – but your current perceptual experience by itself does not present the hour hand as moving. By contrast, it certainly *seems* that you can just perceive, without having to rely on memory or inference, the second hand's motion. Now this may not be right – it might be the case that though this is how it seems, it is nevertheless true that you don't really perceive the motion but only infer it, even in the case of the second hand sweeping around the clock face or the ball rocketing toward the goal. I shall, however, proceed on the assumption that in such cases we can *perceive* the motion.

Since motion only manifests over a temporal interval, then on the assumption that we can perceive motion, the content of perceptual experience, what is experienc*ed*, must include a temporal interval. The specious present doctrine, made famous by William James (1890), is one way to capture this.

> Our feelings are not thus contracted, and our consciousness never shrinks to the dimensions of a glow-worm spark. *The knowledge of some other part of the stream, past or future, near or remote, is always mixed in with our knowledge of the present thing.* (James, 1890, p.606)

> … the practically cognized present is no knife-edge, but a saddle-back, with a certain breadth of its own on which we sit perched, and from which we look in two directions into time. The unit of composition of our perception of time is a *duration*, with a bow and a stern, as it were -- a rearward -- and a forward-looking end. It is only as parts of this *duration-block* that the relation of *succession* of one end to the other is perceived. (James, 1890, p. 609-10)

James' own treatment of the specious present doctrine is beyond the scope of this paper. What is relevant for present concerns is that it is an alternative to the idea that the content of experience is content corresponding to an instantaneous state of some event in the world. On the specious present doctrine, the primary contents grasped in experience are contents corresponding to temporally extended processes. The magnitude of the temporal interval involved differs depending on the author one consults: James thought it was in the neighborhood of 6-12 seconds, others have argued for a fraction of a second. Whatever the magnitude, this doctrine provides for a possible explanation of the capacity to perceive the motion of the second hand, but not the hour hand. The temporal duration spanned by the experience has sufficient magnitude that the spatial displacement of the second hand within that interval is noticeable; whereas the hour hand's displacement during that interval is not noticeable.

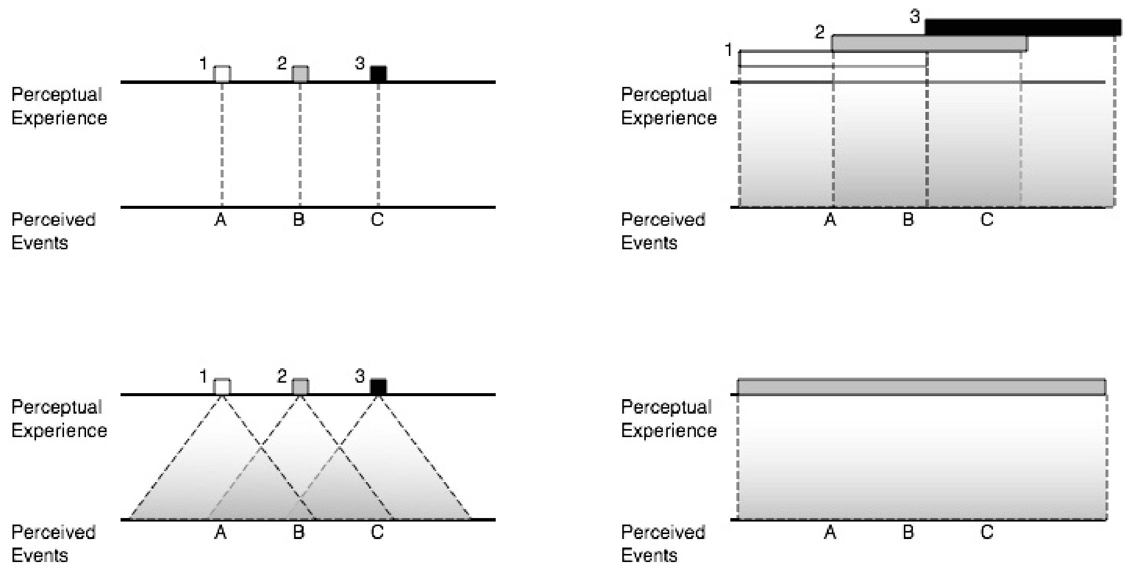

Figure 1. Four ways to understand the temporal relationship between perceptual experience and perceived events (these are not the only possibilities). See text for explanation.

This is illustrated on the top left and bottom left parts of Figure 1. The standard view is illustrated in the upper left. As time progresses there is a sequence of distinct perceptual states, labeled 1, 2, 3, such that each is a representation of a state of the environment, labeled A, B, C. These might be different locations of the second hand. While each of the successive perceptual states represents a successive location of the second hand, none of the perceptual states is able to represent motion. The other three diagrams on Figure 1 are different interpretations of the specious present doctrine. One interpretation of the specious present doctrine is illustrated on the bottom left: as time progresses, there is a sequence of distinct perceptual states, labeled 1, 2, 3, such that each is a representation of a temporally extended environmental trajectory. Perceptual state 1 is a representation that includes events A and B; perceptual state 2 is a representation that includes events A, B and C; and so forth. Because of this, motion can be perceived.

Before moving on, a common misunderstanding must be cleared up. One standard objection to the specious present doctrine is that it misrepresents the facts of perception, since if what is perceived at any time is a trajectory, then what would be perceived would not be motion, but a static image analogous to a time-lapse photograph. While perhaps some proponents of the doctrine over the last century have conceived of the specious present doctrine this way, this is not the way it should be understood. Rather, it should be interpreted this way: perceptual state 2 represents environmental states A, B and C, but it does *not* represent them as simultaneous. If it did represent them as simultaneous, then the result would be analogous to a time lapse photograph. But it represents A, B and C as successive.

Now as I've described the specious present doctrine, there are two ways to understand the relation between the temporality of the experiencing and the temporality of the experienced. The interpretation that I have already discussed andd is illustrated on the bottom left of Figure 1 is that at any instant, the content of experience is of a temporally extended interval. Another possibility is that acts of conscious experience are themselves necessarily temporally extended. On this view, there is strictly no content grasped at time (instant) *t*; rather, the content grasped in experience is temporally extended because acts of conscious experience are themselves temporally extended. This view was articulated by Stern (1897), and more recently by Barry Dainton (2000). There are two ways to understand this proposal, and they are diagrammed in the upper right and bottom right parts of Figure 1. I will return to these two ways of understanding SP in Section 5.

3. Temporal illusions

In this section I will discuss a few phenomena that raise questions about the temporality of our experience: the cutaneous rabbit, apparent motion, and representational momentum. I will take each in turn.

The cutaneous rabbit phenomenon is as follows: Geldard and Sherrick (1972) placed small mechanical devices at various places on subjects' arms and shoulders that would produce sequences of small taps, the exact nature and timing of these sequences under the control of the experimenters. Some of the sequences lead to no surprising results: a sequence of taps all located at the same spot on the wrist, for example, will be reported by the subject as a sequence of taps at the same location at the wrist. But different sequences induced an odd illusion:

> "… if five brief pulses (2-msec duration each, separated by 40 to 80 msec) are delivered to one locus just proximal to the wrist, and then, without break in the regularity of the train, five more are given at a locus 10 cm centrad, and then another five are added at a point 10 cm proximal to the second and near the elbow, the successive taps will not be felt at the three loci only. They will seem to be distributed, with more or less uniform spacing, from the region of the first contactor to that of the third." (Geldard and Sherrick 1972, p. 178)

This might seem like a merely spatial illusion, since what is being inaccurately represented in the second case is the location of many of the taps. The second tap of this sequence is felt not on the wrist, but a few centimeters proximal to the wrist. But there is a puzzling temporal aspect to the illusion as well that can be brought out by asking: where does the subject feel the second tap *when the second tap is produced*? The answer seems to be: if in the immediate future there will be only more taps at the wrist, then the second tap will be felt at the wrist; but if in the future an appropriate sequence of taps will be delivered to the forearm and elbow, then the second tap will be felt a few centimeters proximal to the wrist. This *seems* to be the right answer, but at the time of the second tap, the subject cannot know what the future sequence of taps will be, since the different possible sequences are randomly selected. Though this answer seems right, it requires that the perceptual system can look into the future, see where the subsequent taps will be delivered, and use that information to decide how to interpret the location of the current tap!

The next example is a phenomenon that has recently been found (Williams et al., under review). First, consider bi-stable quartet of flashing dots, as in Figure 2 (Gengerelli, 1948). When the top and bottom dots flash, followed by a flash of the left and right dots, the resulting apparent motion will be seen either as (a) the top dot moving down and to the left, with the bottom dot moving up and to the right (counterclockwise motion indicated by the solid-line arrows); or (b) the top dot moving down and to the right, with the bottom dot moving up and to the left (clockwise motion indicated by the dotted-line arrows). A diamond orientation bi-stable quartet is perceived as clockwise motion about half the time, and as counterclockwise about half the time (Ramachandran & Anstis, 1983).

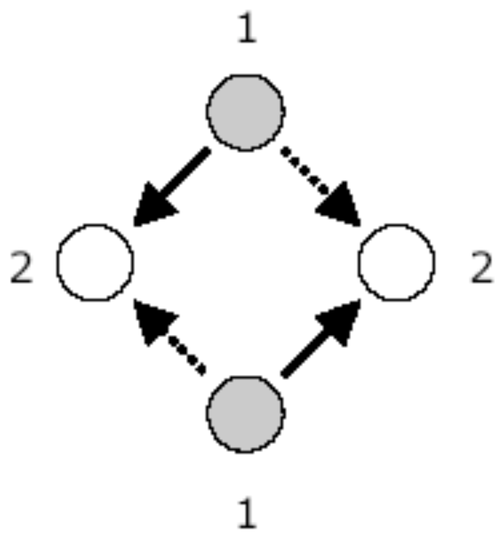

Figure 2. An ambiguous bi-stable quartet of flashing dots. First, the upper and lower dots (labeled '1') flash simultaneously, then the left and right dots (labeled '2') flash. The resulting apparent motion is either clockwise (dotted-line arrows) or counter-clockwise (solid-line arrows).

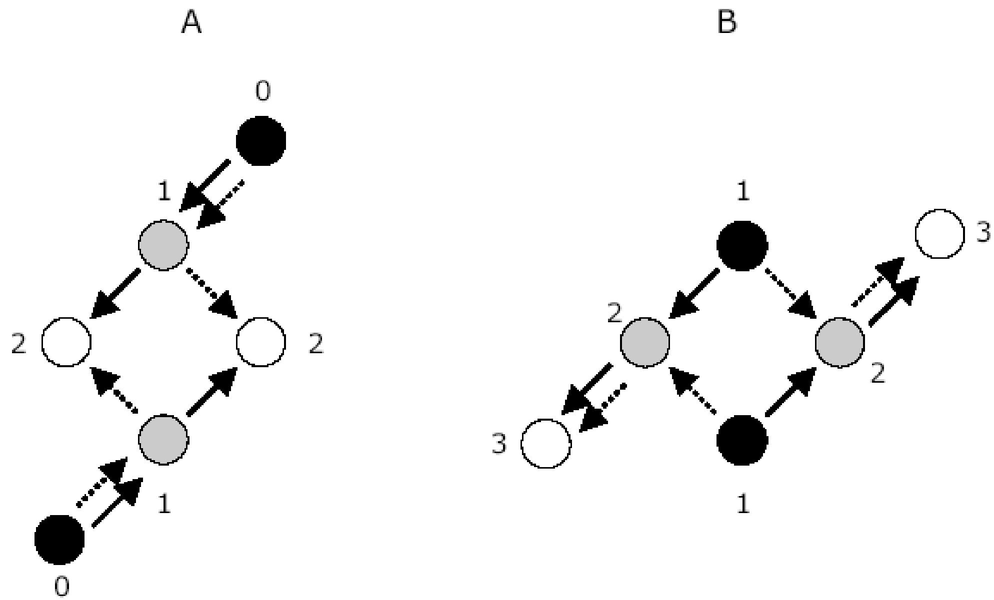

Figure 3. Apparent motion retrodiction. See text for explanation.

Next, consider how adding a third pair of flashing dots, either before or after the quartet, can influence how the motion of the quartet is perceived. First, if the third pair flashes before the quartet, as in the left side of Figure 3. In the situation diagramed, before the four dots in the quartet flash, a third pair outside the quartet, labeled ‘0’, are flashed. The sequence of dot flashes could yield two possible apparent motion sequences. First, the motion from the two external dots to the top and bottom dots, labeled ‘1’, on the quartet could be followed by counterclockwise motion of the quartet, yielding two perceived rectilinear apparent motions as indicated by the solid-line arrows. Second, the motion from the ‘0’ dots to the top and bottom dots could be followed by clockwise motion of the quartet, yielding two perceived left-hand-turn movements as indicated by the dashed-line arrows. Perhaps not terribly surprisingly, the visual system has a preference for rectilinear motion (Ramachandran & Anstis, 1983), and so the rectilinear path of the apparent motion is seen significantly more than 50% of the time in this condition.

The phenomenon illustrated on the right hand side of Figure 3, where the third pair, labeled '3', flashes *after* the quartet, is yet more interesting. The first two pairs of dots that flash are identical to the pairs that flash in the ambiguous bi-stable quartet. However, after these dots, a third pair flashes. As in the previous case, there are two possible paths of apparent motion: a rectilinear path (indicated by the solid-line arrows), and a left-hand-turn path, indicated by the dashed-line arrows. Since it is known that the bi-stable quartet *by itself* will produce the clockwise and counter-clockwise apparent motions with equal probability, it might be expected that the rectilinear path and the left-hand-turn path should be perceived with equal probability – if on a given trial the subject perceived the quartet as clockwise movement, the movement to the '3' dots would be perceived to be a left hand turn; and if the quartet is perceived as counter-clockwise motion, then the motion to the '3' dots would be perceived as rectilinear motion. However, the result is that when the successive pairs of dots followed each other at 67 msec or less, rectilinear motion was perceived significantly more than 50% of the time (see Williams et al. (under review) for details, including the strength of the effect, and how the strength varies as conditions are modified; for trials in which the interstimulus interval was 100 msec, no significant effect was found). This means that there are some trials such that if no third pair flashes, the subject sees the initial quartet as clockwise motion, but if upon the flashing of the third pair the subject sees the initial motion as counter-clockwise!

Next, I wish to discuss a third phenomenon. The original Geldard and Sherrick article briefly mentions, like an afterthought and without further exploration, that "there is typically the impression that the taps extend beyond the terminal contactor" (p.178). This effect – the apparent continuation of some perceived stimulus motion beyond its actual termination – has been studied a great deal under the rubric of *representational momentum*. A typical stimulus set together with its perceived counterpart are shown in Figure 4.

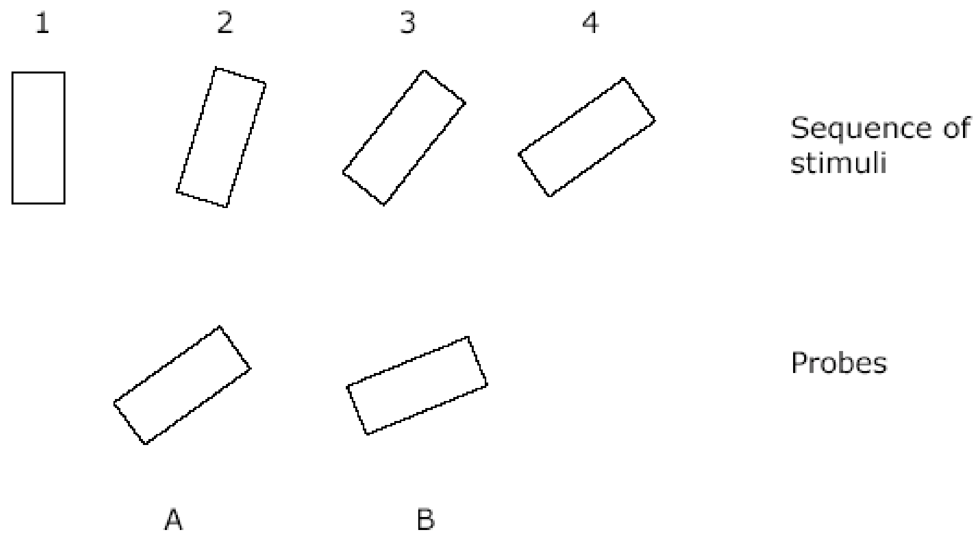

Figure 4. Representational momentum. A sequence of stimuli is shown to subjects, such as a moving ball or a rotating rectangle. The sequence is ended by a masking stimulus. Subjects are then shown two probe stimuli, such as two different end locations for the rectilinear motion, or rectangles oriented at different angles for the rotating motion, and are to select the one that matches the last stage of the movement that they observed. Subjects overshoot by preferring probes that slightly overshoot the actual terminus to those that accurately mirror the terminus. For review see Thornton and Hubbard (2002).

While there are many possible explanations for this phenomenon, it certainly suggest that at some level the perceptual system produces representations whose content anticipates, presumably on the basis of the current observations and past regularities, what the perceived situation will look like in the immediate future.

Finally, consider the unbeatable rock-paper-scissors machine (Jacobson, 2005). There are two phases to the experiment. First, in the training phase, subject play RPS with a computer: upon the completion of a numerical countdown, subjects press one of three bottons corresponding to rock, paper, or scissors, and the subject's choice is displayed on the monitor. At the same time, the computer produces, randomly, rock paper or scissors, and this is also displayed on the monitor at about the same time as the subject's choice (depending on how quickly the subject presses the button, the subject's choice may be slightly ahead of, or behind, the computers). Subjects are told that during this phase, the computer is learning the subject's tendencies. Really, though, the program is slowly introducing a delay between then the subject presses the button and when the subject's choice is displayed on the screen. At the end of the 'training' period a delay of about 100 msec is introduced without the subject noticing. Then subjects are told that the real game is beginning. A countdown appears on the screen, and subjects press one of three buttons; the computer then determines which choice will defeat the subject's choice, and displays this choice on the screen; then just a few tens of milliseconds later, the subject's choice is displayed on the screen. As described it is no mystery why the computer can always win. Anyone allowed to see an opponents choice before choosing will always be able to win. But, to the subject it looks as though the computer makes its choice before the subject does. When the countdown reaches zero, it seems to the subject that the subject begins pressing one of the buttons, the computer's choice then appears before the subject's button press, but too late for the subject to change which button he is about to press, and then the subject's choice appears on the screen. That is, even though in fact the subject presses the button before the computer makes and displays its choice, it seems to the subject as though the computer's choice is on the screen just before her own button press!

What these phenomena seem to indicate is that the temporal content of what we experience – that is, when the events we perceive occur, and the relative temporal relations between these events – is not merely a passive registering of the temporal features of the events themselves, at least not on the short time scales up to a few hundred milliseconds or so. Rather, the temporal content of experience at this scale is to some extent a construction. The perceptual system uses information about regularities it expects in the perceived environment to interpret, and in some cases overrule, what incoming sensory information suggests. Because continuous evenly spaced motions are more common and more likely than discrete sets of spatially separated stimuli, the sequence of taps in Geldard and Sherrick's experiment is interpreted as evenly spaced taps; because rectilinear motion is more likely than motion that quickly changes direction for no reason, the subjects in the Williams et al. study see the rectilinear motion more often, by re-interpreting the motion of the first two pair of dots, after the third pair of dots flashes; and because the perceptual system assumes that its motor actions are simultaneous with their environmental effects (in this case, the button press and the choice appearing on the screen), subjects can be induced to mis-construct the timing of their own actions.

4. The trajectory estimation model

In this section I will describe, in qualitative terms, a way to understand how perceptual experience is constructed at the brief scale of around, at most, a few tenths of a second. This alternative, which I will call the *trajectory estimation model*, will be able to account for the various phenomena discussed in the previous sections.

The first step is to distinguish between two different kinds of representational state involved in experience, *sensation* and *perception*. Unfortunately these terms are loaded with hundreds of years of theoretical baggage, and I don't mean to import that baggage here. All I want to do is to distinguish, on the one hand, information that is picked up by the sense organs from the interpretation that is eventually reached, in part on the basis of what is picked up by the sense organs. For example, when looking at a Neckar cube, the sense organs pick up information about 12 co-planar line segments – this would be a matter of *sensation.* However, three different things might be *perceived*: two different cube orientations, or (with a bit of effort) 12 co-planar line segments.

The job of perception is to produce a representation of the environment, preferably an accurate representation of the environment. The sensory information by itself is often noisy and incomplete, sometimes even contradictory, and so the perceptual system must make use of certain kinds of knowledge in addition to the sensory information in order to arrive at a decent perceptual interpretation. The process of perception, then, can be seen as attempting to strike a balance between on the one hand what the noisy, incomplete, and contradictory sensory information indicates is happening, and on the other hand the sort of things that the perceptual system thinks is likely to happen in the environment. For example in Figure 5A, the sensory information indicates that there is a disk flanked by two bar segments. However, the perceptual system assumes that it is very unlikely that there are two separate but aligned bar segments flanking an object, and interprets it as a single bar that is partially occluded by the disk (5B) as opposed to a disk overlaying the ends of two accidentally aligned short bars (5C).

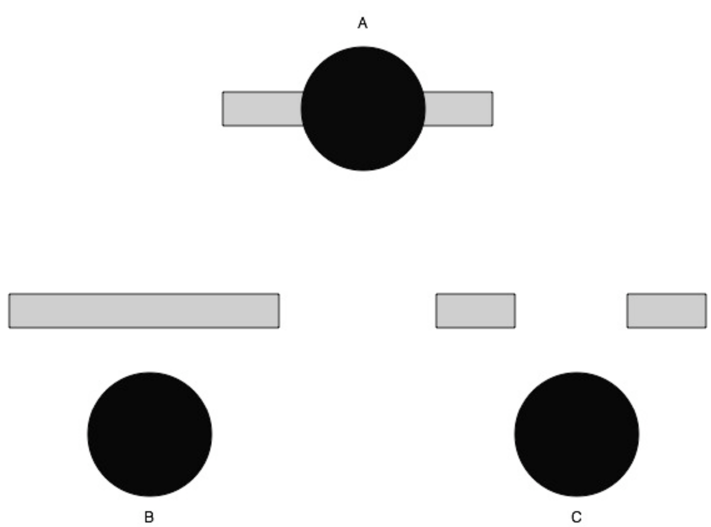

Figure 5. Perceptual interpretation of sensory input. See text for explanation.

What I have just said about perception is not too surprising (though it is controversial, every twenty years or so a new group of perceptual minimalists arise who quarrel with this view – but engaging in that debate is beyond the scope of this project). While the details differ, the basic idea that perception involves constructing representations that are based, in part, on sensory information, is fairly standard, and has been for some time. But part of this standard view has been that the job of the perceptual system is to produce representations of *states* of the environment. I want to suggest, though, that we should reconceive the job of the perceptual system as producing representations that attempt to capture temporally extended *processes* (or, synonymously, *trajectories*) in the environment. On this way of thinking of things, what is typically taken to be perceiving a state is in fact perceiving a degenerate trajectory. For example, when looking at a scene as depicted in Figure 5A, it might be common to assume that the content of what is perceived is a state, in this case a relation between two objects, a bar and a disk – something like *a bar behind a disk*. However, on the view I am recommending, what is actually perceived is a degenerate process, namely the *continuation through time* of a certain spatial relation between the bar and disk. The sensory information upon which this interpretation is based includes not only the information about the disk shape and the two aligned bar-segments, but also information picked up over time – tenths of a second to maybe a few seconds, depending on how long you look at the figure – to the effect that this configuration is not altering.

To summarize: the perceptual system is constantly producing estimates not of states of the environment, but of environmental *processes*. Specifically, this is to be understood as the proposal that at each time t, the perceptual system is producing an estimate of what will is happening over the interval $[t-j, t+k]$, for fairly small j and k. So for example suppose that we are dealing with discrete time units, and j and k both are 2. In this case, at time t=7, the perceptual system produces an estimate of the process's evolution from time t=5 to time t=9. I will return to the magnitude of this interval in the final section. In this section I want to describe the basics of how the model applies to the sort of cases described in previous sections.

Recall in Section 2 I drew a distinction between the time of the represent*ing* and the time of the represent*ed*. It will be helpful to codify this distinction as follows. Let's call the perceptual representation constructed *p*. I will put, in a subscript to *p*, a numerical indication of the time represented by the representation, and the time at which the representation is produced. For example, $p_{2,3}$ is a perceptual representation that represents something that happened at time *t*=2, while the representation itself is produced at time *t*=3. On the trajectory estimation model, we will have representations of the form $p_{[5,6,7,8,9],7}$. This is the perceptual representation, produced at time *t*=7, of a process from *t*=5 to *t*=9.

It may help to walk through an example of how the trajectory estimation model deals with one of the phenomena. I will use the cutaneous rabbit as an illustration. It will be sufficient to discuss what is happening at two times, *t*=5, which is just after the first five impulses are delivered to the wrist; and *t* = 10, which is just after the second group of five impulses is delivered to the forearm. First, at *t* = 5, the perceptual system has received as sensory input five impulses at the wrist. At this time, there is no reason to suspect that the sensory information is suspect, and so the trajectory that is represented at t = 5 is that there has just been a sequence of five taps at the wrist. Before moving an, though, recall the representational momentum effect. Given this, perhaps a better characterization of the trajectory estimate at that time is that there have just been 5 taps at the wrist and there is about to be more taps at the wrist. Now what about the estimate produced at *t* = 10? At this point, the sensor information indicates that there have been two spatially distinct but temporally adjacent groups of taps, five at the wrist followed by five on the forearm. The perceptual system evidently takes it that this is an unlikely thing to have occurred, and interprets it as an evenly spaced sequence of impulses that were very imperfectly sensed by the sense organs. So at t = 10, the perceptual system produces an estimate according to which an evenly spaced sequence of impulses was just delivered between the wrist and forearm. The estimate that was produced at t = 5 is no longer in play, it is forgotten. Because of this, if the subject were probed at t = 5 for what was perceived (or if the sequence of impulse had ended at t = 5, and so no re-interpretation were induced), the subject would respond that the second impulse was felt at the wrist. However, if probed at t = 10 or later, the subject will report that the second tap was felt just proximal to the wrist. So even though *at the time of the second impulse* the subject perceives it to be at the wrist, at the time of the tenth impulse, the subject has no recollection of this prior interpretation, and rather has a perceptual state to the effect that there is currently a sequence of impulses, the second of which was just proximal to the wrist.

5. Discussion and conclusion

The trajectory estimation model has been defended against competing accounts on the basis of two phenomena: our ability to perceive motion (our abililty to see the second hand's motion is different from our capacity to tell that the hour hand is moving), and the existence of temporal illusions. The first indicates that the content of our perceptual experience must include at least a brief temporal interval; and it is this that indicates that the trajectory estimation model is to be preferred over the traditional view. And the second indicates that the details of how this interval is perceived is a matter of interpretation and construction, and in particular that it can be re-interpreted; and it is this that indicates that the trajectory estimation model is to be preferred over the Stern/Dainton account which seems unable to account for temporal illusions. It is to this last claim that I turn next.

How might a defender of the Stern/Dainton view attempt to handle temporal illusions? Let's return to Figure 1, and take the perceived event to be apparent motion, and so A will be the first flash, B will be no stimulus, and C will be the second flash. On the traditional view, perceptual state 1 is a perception of the first flash, perceptual state B is a perception of nothing, and perceptual state C is a perception of the second flash; but after the second flash, the subject's memory somehow gets involved and the subject misremembers what happened, and in particular is inclined to report later that she perceived a stimulus between the location of the two flashes. I won't argue against this view, other than to remark that it is unnecessary given the trajectory estimation model, and seems independently implausible.

On the trajectory estimation model, perceptual states 1 and 2 both represent only a single flash, but perceptual state 3 represents continuous motion between the first and second flash. The main difference between this and the traditional model is that the traditional model must posit that perception and memory are always involved, even for events on the order of a tenth of a second.

Now what about the Stern/Dainton account? There are two ways it can be spelled out. Consider first the bottom right part of Figure 1. Here there are no discrete perceptual states. Perceptual experience is something just extended through time, and any given chunk of perceptual experience has a corresponding temporal chunk of environmental processes as its content. But this seems unable to account for temporal illusions. Such illusions require us to recognize that at different times there can be different interpretations of what happened. So in the case of apparent motion we know, for example, that after the first flash but before the second flash, the subject does not perceive there to be any stimulus anywhere, and so at this time the chunk of perceptual experience would have to be that there was only a brief flash. But at the time just after the second flash, the subject perceives the second flash to be the termination of a quick motion that traversed spatial locations between the two flashes. These are inconsistent. But if at the two times it is the same chunk of perceptual experience that corresponds to what is happening at the time between the two flashes, then they are the same, and can't be inconsistent.

One way that a proponent of this view might respond would be to say that different interpretations are the result of different intervals of experience. This is the upper right illustration on Figure 1. Here perception continues, but different intervals of it might embody different interpretations. For example, chunk 1 includes the first flash and post flash emptiness, but not the second flash; chunk 2 includes both flashed. And while chunk 1 and chunk 2 overlap, they are different chunks, and hence might embody different interpretations. This view however seems untenable, since it must hold that at any given time there are many, possibly inconsistent, perceptual states. For example, at the time between events A and B, the subject is in two different perceptual states, chunk 1 *and* chunk 2. There are further problems with this proposal (such as its inability to say anything about representational momentum) but exploring those is beyond the scope of this paper.

Finally, notice that the phenomenon of perceptual re-interpretation and representational momentum allow us to get a rough idea of what the magnitude of the temporal interval of the estimated trajectory is. The apparent motion retrodiction of Williams et al. (and this is consistent with other similar phenomena) seem to indicate about 100 milliseconds as the backward extent of this window. When, for instance, the third pair of dots flashes, but does so more than 100 milliseconds after the quarter (see Figure 3) subjects don't exhibit the phenomenon. That is, whichever direction the motion was initially seen as in the quartet, at stays that way. It is only for intervals of less than 100 millisecond at which subjects can re-interpret the original motion, and in such cases they also never recall having a different interpretation. Accordingly, it seems plausible to set the past-directed end of the trajectory estimate at about a tenth of a second. And this also would then be the point at which perception proper ends and something more like memory begins. So, any motion swift enough that it traverses spatially discriminable locations within this interval would be perceived motion, whereas anything moving so slowly that upon the passing of a tenth of a second its location is not discernibly different, will not be perceived to move (though one can still tell that it is moving by comparing its location as perceived to its location as remembered, from a few seconds ago to (in the case of the hour hand) many minutes ago. The phenomenon of representation momentum seems to suggest that the future-directed end of the trajectory estimate reaches about 100 milliseconds into the future, since this is roughly about how much time it would take the object to actually traverse the distance that it is judged to have traversed. But in both cases – the past-directed magnitude and the future-directed magnitude – there is variation in the psychological results that makes pinning the magnitude down further very difficult. Suffice it to say that both ends are between say 50 and a few hundred milliseconds.

The goal of this brief paper has not been to construct a knock-down argument for the trajectory estimation model or the details of its character or magnitude. Rather, the goal has simply been to indicate roughly some phenomena that appear to call into question the traditional way of understanding the temporality of experience, and to describe qualitatively a few alternatives to this traditional understanding, and finally to provide some reasons why one of these alternatives looks better able than the others to account for the phenomena. This is, however, an active and growing area of research both philosophically and scientifically, and so making any definitive pronouncements would be premature at this time.

Further Reading:

Dainton, Barry (2000). *Stream of consciousness : unity and continuity in conscious experience*. New York: Routledge. A nice discussion of philosophical work, including some historical discussion of the specious present doctrine and Husserl's phenomenology of time consciousness. A decent all-purpose introduction to the general philosophical debate.

Dennett, D. C., & Kinsbourne, M. (1992). Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences* 15(2):183–247. This is a fascinating article that discusses many temporal illusions, and presents a model, the multiple drafts model, that is different from, but consistent with, the trajectory estimation model presented here. This article is highly recommended.

Eagleman, D. M., & Sejnowski, T. J. (2000). Motion integration and postdiction in visual awareness. *Science*, *287*, 2036–2038.

Freyd, J.J., & Finke, R.A. (1984). Representational momentum. *Journal of Experimental Psychology* 10:126–132. This is the classic statement of the representational momentum finding.

Geldard, Frank A, and Sherrick, Carl E. (1972). The Cutaneous "Rabbitt": A Perceptual Illusion. *Science* 178(4057):178-179. This is where the cutaneous rabbit phenomenon was first published.

Grush, Rick (2005). Internal models and the construction of time: generalizing from *state* estimation to *trajectory* estimation to address temporal features of perception, including temporal illusions. *Journal of Neural Engineering* 2(3):S209-S218. Here I develop the trajectory estimation model in much more detail, intended primarily for neuroscientists and psychologists, but philosopher should be able to follow it.

Grush, Rick (2005). Brain time and phenomenological time. In Brook and Akins eds. *Cognition and the Brain: The Philosophy and Neuroscience Movement*, pp. 160-207, Cambridge: Cambridge University Press.

Husserl, Edmund (1966). *Zur Phaenomenologie des inneren Zeitbewusstseins [1893-1917]*. Herausgegeben von Rudolf Boehm, Husserliana X, The Hague. A landmark philosophical work, in the phenomenological tradition, investigating the nature of our experience of temporality.

James, William (1890). *Principles of Psychology*. New York, Henry Holt. Chapter 15, on the experience of time, is where James discusses the specious rpesent doctrine. This is the locus classicus for that doctrine.

Kolers, P. A. (1972). *Aspects of Motion Perception.* London: Pergamon Press.

MacKay, D. M. (1958). Perceptual stability of a stroboscopically lit visual field containing self-luminous objects. *Nature* 181:507–508. A nice discussion of phenomena such as apparent motion.

Ramachandran, V. S., & Anstis, S. A. (1983). Extrapolation of motion path in human visual perception. *Vision Research* 23:83-85.

Rao, Rajesh, David Eagleman and Terrence Sejnowski (2001). Optimal Smoothing in Visual Motion Perception. *Neural Computation* 13:1243–1253.

Sellars, Wilfrid (1968) Science and Metaphysics. London: Routledge. The appendix discusses the specious present doctrine, and develops an intereting, and little known, account of the doctrine.

Stern, William (1897). Psychische Präsenzzeit. *Zeitschrift für Psychologie und Physiologie der Sinnesorgane* 13:325-349.

Thornton, Ian M., and Timothy L. Hubbard (2002). Representational momentum: New findings, new directions. *Visual Cognition* 9(1/2):1-7. This is the introduction to a special issue of the journal *Visual Cognition* devoted to representational momentum.

Williams, L.E., Hubbard, E.M., & Ramachandran, V.S (submitted). Retrodiction in Apparent Motion.