Predictive Coding Is Unconscious, so that Consciousness Happens *Now*

A Reply to Lucia Melloni

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Conscious percepts depend strongly on past events. Expectations, primes, and prior experiences all shape the percept we have at any moment in time. Yet does this imply that conscious experience should be viewed as extended in time—as "flowing"—instead of as just happening now?

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1 To infer or to integrate, that is the question

In her commentary, Lucia Melloni argues that consciousness unfolds in time: there is a stream of consciousness. What I see now is intricately linked to what I have seen before. And what I see now is what I expect to see—much along the lines of predictive coding. A full understanding of consciousness should not neglect this point. There is even a stronger claim that somehow the process of inference over time is crucial to understanding consciousness.

I appreciate the boldness of linking the framework of Bayesian predictive coding to specific stages in the process of generating consciousness:

> One promising framework within which the influence of previous experience can be understood is the Bayesian framework. When applied to perception, each mathematically-formulated ingredient of this framework can be assigned a percep-

> tual counterpart, with previous experience referring to the prior, the current moment referring to the likelihood, unconscious inference referring to Bayes rule (which combines the prior with the likelihood in an optimal way), and the result—our perception—referring to (the peak of) the posterior distribution. (Melloni this collection, p. 4)

To my knowledge, this is the first time this has been so explicitly laid out—writers on predictive coding thus far have always stayed a little vague on where exactly consciousness sits in the Bayesian framework.

Yet at the same time, there is the suggestion of long temporal range integration being the key ingredient of consciousness:

> Event-objects of the conscious mind thus per definition unfold in time and we also act in time: we make use of current and previous input to figure out the most appropriate response predicting their consequences. There is thus a continuum of interdependencies along the time dimension whereby every past moment is integrated with the present and projected into the future, giving rise to the flow of consciousness. The same way we have been thinking about the integration of multiple sources of information within a given moment of time, such as multiple features of a single object, there is thus integration across time. (Melloni this collection, pp. 7-8)

This makes intuitive sense, particularly in the case of moving objects, such as the tennis ball Melloni uses as an example. Indeed it is hard—if not impossible—to pinpoint the exact *now* of conscious experience of such a ball.[1]

Yet the two points seem contradictory. In the Bayesian predictive coding framework, consciousness is the *result* of the unconscious inferential processes. Previous knowledge and experience (the priors) play an important role, but they are combined with current input to produce the posterior, which is conscious sensation. In the second account, however, consciousness seems to be something that is stretched out over time, so that both prior and posterior are smelted into a "flow" of consciousness. I find it hard to reconcile these two views.

2 The latency of visual consciousness is variable

Melloni discusses some impressive experiments that show the crucial importance of prior information and expectation in shaping or simply altering conscious experience (and her example, figure 1, is enlightening and flattering at the same time). In all these cases, however, consciousness is portrayed as the *outcome* or *result* of an otherwise unconscious inferential process. The result may come earlier or later, as in the experiment on letter priming that Melloni describes, resulting in earlier (200ms) or later (300ms) electrophysiological correlates of conscious recognition depending on the presence or absence of appropriate priors. Further experiments are discussed, showing that neural correlates of consciousness may shift (neural) location, depending on expectation and priors. Yet still, the end result—consciousness—occurs at the end of a cascade of neural operations. Consciousness, in this account, may occur at variable moments and locations, but *moments* they are.

These results complement earlier findings that the latency of recurrent processing—and hence the emergence of a conscious sensation—may vary. Super et al. (2001) showed that degrading stimulus quality may increase the latency of recurrent signals to V1 in the monkey visual cortex (see figure 5c of Supèr et al. 2001), and that this affects the latency of behavioral responses of animals that are consciously reporting the presence or absence of the stimuli. Latency of recurrent signals may also vary spontaneously between trials, which correlates with the latency of memory-guided—but not reflexive—saccades to the targets

1 Although some have argued that consciousness unfolds in time as a succession of static frames, more or less like the single frames of a movie—even at specific frequencies, namely 10Hz and 40Hz (Van Rullen & Koch 2003).

that elicit these recurrent signals (Supèr et al. 2004). In humans, the latencies of electrophysiological correlates of recurrent processing also vary, either spontaneously or depending on stimulus properties (Jolij et al. 2011), or depending on the IQ of the subject (Jolij et al. 2007). Likewise, this has consequences for the latency of conscious sensations. The Jolij 2011 study, for example, found that variations in the latency of recurrent EEG signals covary with variations in subjective simultaneity of the stimuli evoking these signals.[2] These results invariably imply that consciousness arises at a particular *moment* in time. That moment may vary from stimulus to stimulus, from trial to trial, from person to person, from prior to prior. But nothing is flowing or stretched out over time.

3 Consciousness is not streaming, but taking snapshots

One may argue that these findings are all obtained with stimuli that are presented *de novo,* using the classic stimulus-onset paradigms. In normal vision, things don't suddenly appear out of nowhere. Or do they? We naturally make about three saccadic eye movements per second, and each time the eye lands on a "new" scene which is—from a retinotopic point of view—radically different from the previous one. In between, we are blind due to saccadic suppression. Moreover, little information seems to be transferred from one view to the next, although some (attended) neural representations seem to be *remapped* across saccades (see Bays & Husain 2007, for an overview of trans-saccadic memory and neural remapping). Such a remapping may allow for a more efficient saccade from one object to the next, when both were already present before the first saccade was made. The predictive coding framework seems to re-emerge in this context: objects that were present or attended on a first fixation form a sort of prior for the representation that is built during the second fixation (which may then arise more rapidly).

Melloni further claims that previous experience has different effects on what is perceived now depending on the temporal interval between prior and current experience. Bistable percepts show hysteresis or adaptation depending on these temporal intervals, or depending on whether the previous experience was conscious or not. But again, I fail to see how these findings support the idea that consciousness is stretched out over time instead of just happening *now.*[3]

So I appreciate the importance of the predictive coding framework. Previous experience plays a very important role in the conscious sensations we have, and the why and how of this is extremely important for fully understanding vision. But these contributions are unconscious. Consciousness happens now, and its neural correlates are likewise limited in time. Consciousness of the past we call memory.

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2 For this reason, I don't quite understand why Melloni suggests that I am claiming that consciousness arises at a particular and *fixed* moment in time. My claim is only that it comes *after* feedforward processing, and as soon as recurrent processing emerges—which may vary.

3 Of course there are visual percepts that are more or less defined by their temporal sequence, the prime example being motion. But this does not imply that the perception of motion is flowing. The first thing the brain does in detecting motion is to convert the flow of motion into a discrete and momentary signal, indistinguishable from how the brain represents other features such as orientation, color, or shape. As a result we see motion now, and instantaneously, which is also crucial for our survival: perceiving something moving in the shadows of a bush (e.g., a snake) needs to be translated into action as soon as possible (e.g., running away). No time for any flow there.

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