We have discussed the concepts of the Bayesian Brain and Predictive Coding (or Predictive Processing) in a series of 3 video lectures (now available at https://vimeo.com/ondemand/behavioralhealth2000/). Click here for two excerpts that will help with our discussion:

Dr. Raese Lectures: The hollow Face Illusion
https://youtu.be/HMWu76YYKvs

Dr. Raese Lectures: Bayes’ Formula
https://youtu.be/KSr5-Uyfo74

1. Two recent encounters prompted me to post this blog:
   A new book by Andy Clark has appeared (Clark, 2016) that provides a brilliantly written summary of the state of the art of this line of thinking. The book is an extension of an influential paper by Clark, A. (2013) that prompted a great number of commentaries from the philosophy-of mind-community.

2. The second prompt for this post is a series of YouTube videos (https://www.youtube.com/watch?v=PIfDqAe3IEg&list=PLiDYw1G3ZEaJHb-LN3cBrcJspQrA69HS), originating from a cruise ship sailing the icy waters of Greenland. The list of passengers-discussing cutting edge issues in mind/brain thinking-is a who’s who of the neurophilosophy field (Andy Clark, Daniel Dennett, Patricia and Paul Churchland, David Chalmers, Derk Perebom, Jesse Prinz and others).

So what is the core message that this group of intellectual firepower wants to bring across?

Here is my take: our deeply held intuitions about how our mind/brain operates-which are so obvious to us-are totally wrong.

There are parallels to this wrongheadedness in our convictions about our own mind in the way we used to be sure of the obvious fact that the sun is going around the earth (you can see it rise in the east, overhead midday and set in the west). We also knew that the length of an interval of time or the length of a ruler is the same for every observer-
until Einstein showed that this obvious fact is just not true. Without his Special Theory of Relativity (1905), the GPS in your iPhone would lead you far astray. We believed that we were different from all other living creatures which made us feel very special—until Darwin (and later the molecular biologists) dethroned us and told us that we are here as a result of an unlikely chain of events that could have had many different alternative outcomes, i.e., we are here contingently—by accident.

In 1995 Patricia Churchland et al (1995) demolished the intuitively obvious idea that the brain is like “a cognitive couch potato (in Andy Clarks words) waiting for stimulation to come in from the external world. When it comes in, it proceeds to process it step by step, layer of the hierarchy by layer of the hierarchy. What Predictive Coding offers is a kind of opposite, the most extreme opposite to the cognitive couch potato view of the brain.” Instead, the job of the brain is to predict the incoming signal and it predicts that signal over many scales of space and time. This is how the dog catches the Frisbee!
Here is Andy Clark (Clark, 2013):

One of the brain’s key tricks, it now seems, is to implement dumb processes that correct a certain kind of error: error in the multi-layered prediction of input.

In mammalian brains, such errors look to be corrected within a cascade of cortical processing events in which higher-level systems attempt to predict the inputs to lower-level ones on the basis of their own emerging models of the causal structure of the world (i.e., the signal source). Errors in predicting lower level inputs cause the higher-level models to adapt so as to reduce the discrepancy. Such a process, operating over multiple linked higher-level models, yields a brain that encodes a rich body of information about the source of the signals that regularly perturb it.

**Here is the history of this theory** (I am quoting from Andy Clark’s paper):

1. **Such models follow Helmholtz (1860) in depicting perception as a process of probabilistic, knowledge-driven inference.**
   From Helmholtz comes the key idea that sensory systems are in the tricky business of inferring sensory causes from their bodily effects. This in turn involves computing multiple probability distributions, since a single such effect will be consistent with many different sets of causes distinguished only by their relative (and context dependent) probability of occurrence (Helmholtz, 1860/1962).

2. **“Analysis-by-synthesis”** (for a review, see Yuille & Kersten 2006). In this paradigm, the brain does not build its current model of distal causes (its model of how the world is) simply by accumulating, from the bottom-up, a mass of low-level cues such as edge-maps and so forth. Instead, the brain tries to predict the current suite of cues from its best models of the possible causes.

3. **Advances in machine learning**
   The Helmholtz Machine sought to learn new representations in a multilevel system (thus capturing increasingly deep regularities within a domain) without requiring the provision of copious pre-classified samples of the desired input-output Mapping (Hinton, 2007a).

4. **Predictive Coding**
   It is this twist – the strategy of using top-down connections to try to generate,
using high-level knowledge, a kind of “virtual version” of the sensory data via a deep multilevel cascade – that lies at the heart of “hierarchical predictive coding” approaches to perception (Friston, 2005).

5. Prediction error minimization
That way (borrowing from work in linear predictive coding – see below) depicts the top-down flow as attempting to predict and fully “explain away” the driving sensory signal, leaving only any residual “prediction errors” to propagate information forward within the system (Friston, 2010).

6. The Bayesian Brain
One key task performed by the brain, according to these models, is that of guessing the next states of its own neural economy. Such guessing improves when you use a good model of the signal source. Cast in the Bayesian mode, good guesses thus increase the posterior probability (4) of your model.

(4) This names the probability of an event (here, a worldly cause), given some set of prior beliefs and the evidence (here, the current pattern of sensory stimulation). For our purposes, it thus names the probability of a worldly (or bodily) cause, conditioned on the sensory consequences.

Changing predictions corresponds to changing or tuning your hypothesis about the hidden causes of the lower level activity. The concurrent running of this kind of prediction error calculation within a loose bidirectional hierarchy of cortical areas allows information pertaining to regularities at different spatial and temporal scales to settle into a mutually consistent whole in which each “hypothesis” is used to help tune the rest.

As strange as it sounds, when your own behaviour is involved, your predictions not only precede sensation, they determine sensation. Thinking of going to the next pattern in a sequence causes a cascading prediction of what you should experience next. As the cascading prediction unfolds, it generates the motor commands necessary to fulfil the prediction. Thinking, predicting, and doing are all part of the same unfolding of sequences moving down the cortical hierarchy (Hawkins & Blakeslee 2004, p. 158).

7. The Free Energy Formulation
Thermodynamic free energy is a measure of the energy available to do useful work. Transposed to the cognitive/informational domain, it emerges as the difference between the way the world is represented as being, and the way it actually is. The better the fit, the lower the information-theoretic free energy (this is intuitive, since more of the system’s resources are being put to “effective work”
in representing the world). Prediction error reports this information-theoretic free energy, which is mathematically constructed so as always to be greater than “surprisal” (where this names the sub-personally computed implausibility of some sensory state given a model of the world).

YouTube Video on the Free Energy Principle
https://www.youtube.com/watch?v=oa0CBr4MHjE&list=PLw_StyAVxLfAvV52F8uy5zYa9sw4pRpt1

8. Experimental Support for Predictive Coding (Two examples from the visual system)
There is an accumulating body of experimental results consistent with this story. We list here only two examples.
We humans carry around in our heads rich internal mental models that constitute our construction of the world, and the relation of that world to us. These models can be expressed at multiple levels of abstraction, including beliefs about sensory stimuli and the output of our motor programs, or higher-level beliefs about self. Advancing our understanding of the brain’s internal processing states, however challenging, could lead to breakthroughs in understanding states such as dreaming, consciousness, and mental disorders (Meyer K, 2012). Computational theories propose that internal models are broadcast throughout the brain, including to sensory areas of the brain (Clark A, 2013)

Example 1

Muckli et al. (2015) have discovered that the superficial layers of visual cortex V1 receive information when not directly stimulated. This information contains contextual feedback from higher visual areas. The data provide empirical evidence for layer-specific cortical feedback relevant for the neurobiology of predictive coding (see also Pietro and Muckli, 2016).

Example 2

In a novel variation of the apparent motion illusion, Chong et al. (2016) used inducer stimuli that allowed them to show that the motion prediction fed back to V1 contained detailed texture information. The information that they were able to read out from V1 was created by the brain’s prediction about an object’s rotational movement as it moved through the visual field. But, in fact, this experience
of rotation was never present in the sensory input to the brain—it was fabricated by the brain out of acquired world knowledge.

I will follow up in future blog post to unpack the rather stunning implications of this unfolding story, in particular the notion that **all the brain ever does is minimizing prediction errors and that this may explain sensation, action, attention and (perhaps) consciousness itself-in fact, a theory of everything of the brain.**
References

(References in Red are clickable and pop up the PDF file of the paper)


