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A Free energy principle for the brain

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relative chronology of his poems, for the lexicographical problems they pose, and for assessing the connection of his poetic with his religious thought. For a broader perspective on what this all amounts to (and I confess feeling still too close to the data to have a desirable perspective), I look forward to the reactions and insights to be provided by the discussion.

M. Karl FRISTON
Professeur, University College London (Grande Bretagne)

A Free energy principle for the brain

Thursday May 29th : *Action, perception and free-energy*

Value-learning and perceptual learning have been an important focus over the past decade, attracting the concerted attention of experimental psychologists, neurobiologists and the machine learning community. Despite some formal connections; *e.g.*, the role of prediction error in optimising some function of sensory states, both fields have developed their own rhetoric and postulates. In work, we show that perceptual learning is, literally, an integral part of value learning; in the sense that perception is necessary to integrate out dependencies on the inferred causes of sensory information. This enables the value of sensory trajectories to be optimised through action. Furthermore, we show that acting to optimize value and perception are two aspects of exactly the same principle; namely the minimisation of a quantity [free energy] that bounds the probability of sensory input, given a particular agent or phenotype. This principle can be derived, in a straightforward way, from the very existence of agents, by considering the probabilistic behaviour of an ensemble of agents belonging to the same class.

This treatment unifies value and perceptual learning and suggests that value is simply the probability of sensory input expected by an agent. This means that acting to maximise value is the same as acting to minimise surprise; in other words, sampling the environment so that it conforms to our expectations. In this way, exchange or interactions with the environment are maintained within bounds that preserve the integrity of the agent. Clearly, the surprise of a sensory exchange depends on some representation or perceptual model of that exchange. We show that this model emerges naturally as the internal states of the agent optimise the free energy bound above.

This formulation is important because it places the mechanisms of value-learning and reinforcement in the larger context of perceptual learning. For example, conditioning paradigms (both classical and operant) can be regarded as introducing

statistical regularities into the sensorium. These are learned in the same way we learn the causal structure of sensory contingencies. In this view, rewards are simply predictable stimuli (and aversive stimuli are, by definition, surprising). Furthermore, the neurobiological substrates of value-learning become accountable to the larger problem of perceptual inference in the brain. For example, dopamine may not just signal reward but have a much more generic role encoding the conditional certainty or precision of our predictions. This is consistent with a role in modulating the balance between bottom-up sensory information and top-down empirical priors, during perpetual inference.

Friday May 30th : (NeuroSpin) : *Variational filtering and inference*

We present a variational treatment of dynamic models that furnishes the time-dependent conditional densities of a system's states and the time-independent densities of its parameters. These obtain by maximising the variational free energy of the system with respect to the conditional densities. The ensuing free energy represents a lower-bound approximation to the models marginal likelihood or log-evidence required for model selection and averaging. This approach rests on formulating the optimisation of free energy dynamically, in generalised co-ordinates of motion. The resulting scheme can be used for online Bayesian inversion of nonlinear dynamic causal models and eschews some limitations of existing approaches, such as Kalman and particle filtering. We refer to this approach as dynamic expectation maximisation (DEM).

Monday June 1st : *Perceptual inference and learning*

This talk summarizes our recent attempts to integrate action and perception within a single optimization framework. We start with a statistical formulation of Helmholtz's ideas about neural energy to furnish a model of perceptual inference and learning that can explain a remarkable range of neurobiological facts. Using constructs from statistical physics it can be shown that the problems of inferring what cause our sensory inputs and learning causal regularities in the sensorium can be resolved using exactly the same principles. Furthermore, inference and learning can proceed in a biologically plausible fashion. The ensuing scheme rests on Empirical Bayes and hierarchical models of how sensory information is generated. The use of hierarchical models enables the brain to construct prior expectations in a dynamic and context-sensitive fashion. This scheme provides a principled way to understand many aspects of the brain's organization and responses.

Here, we suggest that these perceptual processes are just one aspect of systems that conform to a free-energy principle. The free-energy considered here represents a bound on the surprise inherent in any exchange with the environment, under expectations encoded by its state or configuration. A system can minimize free-energy by changing its configuration to change the way it samples the environment, or to change its expectations. These changes correspond to action and perception

respectively and lead to an adaptive exchange with the environment that is characteristic of biological systems. This treatment implies that the system's state and structure encode an implicit and probabilistic model of the environment and that its actions suppress surprising exchanges with it. Furthermore, it suggests that free-energy, surprise and [negative] value are all the same thing. We will look at models entailed by the brain and how minimization of free-energy can explain its dynamics and structure.

M. David WARNOCK

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Stroke, CV Disease and Chronic Kidney Disease

The incidence of end-stage renal disease (ESRD) is increasing in the United States (US) population USRDS, and the prevalence of chronic kidney disease also appears to be increasing, in parallel with increased surveillance, routine reporting of estimated glomerular filtration rates (eGFR) with the MDRD equation, as well as increasing prevalence of hypertension and diabetes in the general population. These same etiologic factors are also increasing at the global level; the increasing prevalence of CKD in the US population mirrors what is happening at the global level.

There is an increasing realization that CKD is associated with cardiovascular outcome events, and that this association is more marked with more advanced CKD. This association has been described with short-term outcomes in patients with acute myocardial infarction, as well as longer term outcome measures, including mortality rates, hospitalization rates and cardiovascular event rates.

Anemia is frequently associated with CKD, and when present, serves as an independent risk factor for cardiovascular morbidity and mortality associated.

Abramson et al. reported that CKD and anemia (hemoglobin < 12 gm/dl in women, and < 13 gm/dl in men) were independent risk factors for stroke in a middle-aged community-based population in the Atherosclerosis Risk in the Community (ARIC) study, with a relative risk of 7.49 in those subjects who are anemic and had creatinine clearance < 60 ml/min compared to the non-anemic participants with creatinine clearances > 60 ml/min. Similarly, the combination of anemia and CKD has a significant impact on survival after acute myocardial infarction in a study of Medicare recipients in Georgia. There are 3 large samples of patients in the US that provide estimates of the prevalence of CKD, with stratification according to the degree of impairment of kidney function: a) the Renal REGARDS cohort is the focus of our current efforts at the University of Alabama at Birmingham ;