Editorial to the Special Issue on Perspectives on Human Probabilistic Inference and the 'Bayesian Brain'

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Though usually implicit, probabilistic inference (both abductive and inductive) is fundamental to human mental life, to its progressive development, and to directly lived experience. In recent years we have witnessed an explosive growth in studies of probabilistic inference from various perspectives. The timeliness of this topic is clearly demonstrated by the response to Clark's (2013) discussion article in Brain and Behavioral Sciences, which was so extensive that a special issue of Frontiers in Psychology (Cleeremans & Edelman, 2013) had to be created to provide an additional outlet for the exceptionally large number of high-quality commentaries offered. To make optimal use of the impetus raised by these recent results and discussions, we organized a week-long workshop in May 2014 at the Lorentz Center in Leiden, the Netherlands[1]. This interdisciplinary workshop brought together neuroscientists, philosophers, computer scientists and cognitive scientists with the aim to foster new interdisciplinary perspectives on the role of probabilistic inference in three themes: (1) unifying conceptions of brain functioning; (2) mechanisms of phenomenological experience, and (3) the computational realization of cognition. This special issue of *Brain and Cognition* is one of the tangible outcomes of the discussions during and after the workshop. We invited participants to further develop work initiated or inspired by the workshop, and after careful and rigorous reviewing selected twelve research papers and commentaries for inclusion in this special issue.

Several papers address key issues in the *unifying conceptions of brain functioning* theme, from philosophical, information-theoretic, and biological perspectives. Colombo and Wright question the unifying power of the hierarchical predictive processing account, in particular its formulation in terms of the free energy principle. Based on three conditions in philosophy of science that any 'grand unifying theory' necessarily should satisfy (unificationism, monism, and, reductionism), they argue using a dopamine case study that the

[1] http://www.lorentzcenter.nl/lc/web/2014/627/info.php3?wsid=627&venue=Oort

free energy principle cannot reduce and unify leading hypotheses on the functional role of dopamine in the brain. Thornton does not question the unifying character of the predictive processing framework, but questions the Bayesian formulation of explaining away prediction errors. He offers an alternative, purely information-theoretic formulation of predictive processing, based on what he calls ‘infotropic’ measures, and illustrates this formulation using a simulation of a Braitenberg vehicle. Wibral, Priesemann, Kay, Lizier, and Phillips go yet one step further, proposing partial information decomposition as an alternative unifying account of the principles that underpin the operation of the brain. Partial information decomposition was introduced as a recent extension of the more traditional Shannon information theory, allowing to quantify unique, shared, and synergistic information that multiple input channels provide about an output channel. They argue that this framework allows operationalization and comparison among several hypothesized objective functions such as those of prediction error minimization, infomax, and coherent infomax. In a separate contribution, Phillips takes a more bottom-up approach, focusing on the intracellular mechanisms that modulate driving inputs, and exploring the cognitive functions that this modulation is thought to have. In particular he develops the hypothesis that the input to the apical tufts of pyramidal cells in the neocortex is used to amplify the cell’s responses to its feedforward driving inputs. ERP data is used to support this hypothesis, which has been developed further by Phillips et al. (2016). Petro and Muckli also refer to apical amplification, but emphasize its role as potential mechanism for integrating feedforward and feedback inputs. De Bruin and Michael, finally, adopt the prediction error minimization framework, but discuss two competing alternative views (proposed by Clark and Hohwy, respectively) on whether this framework can be reconciled with, or is inherently in conflict with, ‘embodied’ and ‘extended’ conceptions of cognition, further facilitating the debate by explicating the theoretical motivations behind these alternatives that may help to adjudicate between them.

Several other papers in this special issue elaborate on predictive processing and the Bayesian brain as hypothesized *mechanisms of particular (deviations of) phenomenological experience*. Ondobaka, Kilner, and Friston explore the role of the interoceptive (visceral) signals in theory of mind, in addition to the more traditional exteroceptive and proprioceptive signals. They propose that interoceptive predictions contribute to the inferential process of making sense of the internal states that cause another's behavior. Otten, Seth, and Pinto review how the top-down influence of social contextual factors such as desires, goals, socially-determined affective states, and stereotypes on early perceptual processes can be explained quite elegantly within the predictive processing framework. Van de Cruys and Van der Hallen explore, in a follow-up of their proposed mechanistic explanation of autism spectrum disorders as resulting from inflexibly high precision of prediction errors (Van de Cruys et al., 2014), the consequences for the construction and use of generative models if the reducible and irreducible uncertainty in the environment are not sufficiently disentangled by the brain.

Finally, a number of papers in this special issue focus on the *computational realization* of human probabilistic inference in the brain. Kwisthout, Bekkering and Van Rooij propose a computational formalization of predictive processing using discrete causal Bayesian networks, thus allowing for the representation of the structural, non-monotone, non-linear, context-dependent information that is characteristic of higher cognition. With the use of categorical representations for the generative models comes the crucial question on what granularity or level of detail predictions should be made; the trade-off between predictions that are highly informative and predictions that are likely to be correct is recognized as crucial open problem. The special issue is concluded with two overview papers with respect to computational realization. Spratling describes a number of different algorithmic approaches to predictive coding that have been proposed in the literature. These algorithms differ in the way residual errors are computed, generative models are updated, and in the relation of each algorithm to neurobiological aspects. Sanborn, finally gives an overview of the two main approximate approaches to Bayesian inference (sampling approaches such as Markov Chain Monte Carlo sampling and variational approaches such as mean-field approximations), their characteristics, plausible implementations in the brain, and the distinct behavioral biases than can be explained with these approximations.

With this collection of papers, that covers all three themes of the workshop and spans the full interdisciplinary breath (ranging from philosophy and cognitive science to information theory to neurobiology), we believe we can rightfully justify the title of this special issue in providing a wide array of perspectives on human probabilistic inference and the Bayesian brain.

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