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It is my pleasure to provide my strong recommendation for Dr. Carlos Diuk-Wasser for a tenure-track position in the Department of Neuroscience at Brown University. Carlos is an outstanding candidate, uniquely suited for the position you are looking to fill for the following reasons (all described in more detail below): his focus on computational modeling of reinforcement learning and on understanding reinforcement learning in the real world in humans using neuroimaging; his extremely strong interdisciplinary background; his keen and longstanding passion for understanding the neural and psychological basis of human cognition; and his dedication to teaching and mentoring.

Carlos's PhD training was in computer science. However, from the start Carlos was one of few computer scientists who are genuinely interested in understanding human and animal learning – both for its own sake, and in order to bring new insights into machine learning algorithms. In his PhD research, under the mentorship of Prof. Michael Littman, one of the prominent figures in reinforcement learning research, Carlos made great advances in bringing ideas from the ways humans parse tasks to algorithms in reinforcement learning. True to his determination to combine neuroscience and computer science in interdisciplinary research, Carlos also sought mentorship from Prof. Charles Gallistel, an eminent researcher of animal learning at the Center for Cognitive Science in the Psychology Department at Rutgers. Building on these lines of training, Carlos's thesis work focused on explaining how humans can learn to perform difficult real-world tasks, and how decomposition of a task into "objects" – coherent units that involve actions that can be performed on/by them – may be key to solving such problems.

Following this, Carlos made the full transition to cognitive neuroscience, when he came to work at Princeton University with Prof. Botvinick and myself. In this postdoc position, Carlos has been working on fMRI studies of human learning in complex, hierarchical situations, with the aim of uncovering the neural basis of Hierarchical Reinforcement Learning (HRL). HRL is a recent advance in the machine learning literature that aims to alleviate the difficulties of scaling learning algorithms to large, complex tasks. Since real-world tasks are often hierarchical in nature, understanding how humans utilize hierarchical structure to learn them more efficiently holds great promise for understanding human behavior that goes beyond simple conditioning scenarios, and HRL algorithms offer traction for this problem.

In his postdoctoral work, Carlos has investigated many threads of the potential link between the computational theory of HRL and human learning, including: 1) How do humans detect hierarchical structure in tasks, and what aspects of a task are key to identifying useful structure; 2) How does learning proceed concurrently in different layers of the hierarchy; 3) How do task representations utilize the hierarchical structure, and how can this representation facilitate transfer of learning to new tasks. In these projects Carlos combined behavioral and fMRI experiments with computational modeling. In particular, Carlos developed models for learning dynamics, that is, for how experience and feedback in one trial should change behavior in subsequent trials, and used advanced trial-by-trial model-fitting techniques to analyze his experimental data. His key

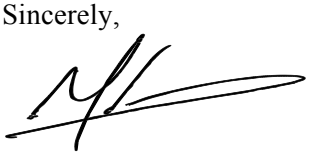
results show that humans can learn concurrently at several levels of a hierarchical task, and, moreover, that reward prediction errors for each level of the hierarchy are *concurrently* available in ventral striatum – the area most strongly associated with what was previously thought to be a *unitary* reward prediction error signal in fMRI. This research is strongly related to, and complements, research done in your department, in particular by Michael Frank and David Badre. Due to Carlos's transition from computer science to cognitive neuroscience and the resulting learning curve, the papers describing the above research are only now starting to come out.

Carlos's postdoctoral work has made optimal and synergistic use of three tools that he brings to his research: behavioral experiments, human functional neuroimaging (fMRI), and computational modeling. Carlos's general approach to understanding the neural basis of learning and decision making involves developing computational models of the dynamics of the learning process, validating and comparing between different such models using trial-by-trial human behavior, and then using the models for sophisticated analyses of fMRI data that are aimed at uncovering the neural structures responsible for the computations needed to solve the task. This combination of methods is especially powerful when studying learning processes whose dynamic nature precludes simple analyses that rely on averaging and traditional statistical tests. Instead, the models embody precise, detailed hypotheses regarding how information on one trial affects behavior in the next trial, hypotheses that are then tested in detail through formal comparison to trial-by-trial data. Once a model is verified against behavior, "hidden variables" of the model (i.e., inner constructs that it supposes, such as prediction errors and subjective values) that are not otherwise available, can be estimated and used for understanding the function of neural areas that are involved in learning. This type of fMRI analysis has become more and more popular in recent years, and work using such a methodology now forms the forefront of research in human learning and decision making. Moreover, Carlos has gone beyond these now almost "traditional" methods of model-based fMRI analysis, to incorporate model-based constructs into multi-voxel analysis methods. This is work that he has only recently begun, but which will surely gain more momentum and will benefit highly from Carlos's strong algorithmic training.

In terms of teaching, Carlos has a truly impressive track record for this early stage of his career, which rests on a diverse array of mentoring and teaching opportunities that Carlos has sought for himself. Carlos's deep interest in and love of teaching are exemplified by the fact that he has successfully mentored students at all levels – high school, college, Master's degree and PhD students – and has taught in several courses, most recently at the Computer Science Winter School at the University of Buenos Aires. Based on the positive responses to his course, he has been invited back to the University of Buenos Aires, to teach a reinforcement learning course as a Visiting Professor this Spring, and to start a collaboration with the Integrative Neuroscience Lab.

In sum, the combination of a formal computer science background, a genuine interest (and proven track record) in cognitive neuroscience, and experience with cutting-edge methods of fMRI analysis make Carlos uniquely well-positioned for a tenure track position in your department. Carlos sees his future lab as sitting squarely within the domains of cognitive neuroscience, and being based on fMRI research, aided by computational methods. I have no doubt that you will benefit immensely from having Carlos on your faculty, and I recommend him highly for this position. Please feel free to contact me if I can be of assistance with more information.

Sincerely,



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