The interpretation of the study by Guo *et al.*[4] also opens an interesting debate on the complex relationship between structural spine changes and functional plasticity, in the form of LTP. In fact, the authors hypothesize that spines represent a substrate for structural plasticity that does not necessarily correlate with functional plasticity. Indeed, the loss of LTP associated with lack of endogenous dopamine was not directly related to the observed structural spine changes. Conversely, the authors attribute to LTP the ability to stabilize newly formed spines.

The analysis of dynamic changes of spine morphology could have implications not only for the pathophysiology of PD, but also for the motor and behavioral side effects related to dopamine replacement therapy of this neurodegenerative disorder. After a few years of treatment, L-DOPA causes a series of hyperkinetic motor symptoms called L-DOPA–induced dyskinesias that limit the use of this therapy. These dyskinesias are thought to be caused by loss of LTP reversal at cortico-striatal synapses[7]. This latter event, also referred to as depotentiation, is usually induced by low-frequency stimulation (1–2 Hz). It represents the ability of an already potentiated synapse to return to control levels and allows the erasure of unessential memory information.

Nevertheless, alterations in spine dynamics at the level of motor cortex could just as well contribute to this disabling phenomenon. Similarly, aberrant plasticity at cortical synapses may be responsible for the impulse control disorders observed during dopaminergic treatment. Impulse control disorders, including compulsive gambling, buying, sexual behavior and eating, are increasingly recognized as serious psychiatric complications in PD[8], and they may be the result of an anomalous interaction between dopamine and glutamate at the level of the cortical spines.

From the clinical point of view, three main aspects should be considered in the interpretation of most of the data resulting from PD animal models, including the study by Guo *et al.*[4]. First, PD is a slow neurodegenerative disorder in which dopaminergic denervation occurs over decades. By contrast, dopaminergic denervation is induced in most preclinical studies by acute neurotoxic lesions. Structural plasticity may differ in these two situations. Second, aging is the greatest risk factor for the development of PD, as well as other neurodegenerative disorders[9]. Yet most experimental studies, including that of Guo *et al.*[4], use young animals, in which plastic events may not be influenced by the different molecular environment that characterizes the aging brain Third, PD is more than just dopamine loss[10]. The widespread, multisystem nature of the neurodegeneration that characterizes PD leads to the involvement of different neurotransmitters, including acetylcholine, serotonin and noradrenaline[11], whose modulation could act in concert with dopamine loss to influence both structural and functional plasticity.

Nevertheless, imaging of spine turnover coupled to electrophysiological analyses of synaptic plasticity and behavioral investigation represents a powerful approach to clarifying the role of the cortex in neurotransmitter-related disorders. Future studies implementing a similar approach in the deeper basal ganglia nuclei might allow the precise description of an integrative model of motor control and subcellular mechanisms underlying movement disorders.

COMPETING FINANCIAL INTERESTS
The authors declare no competing financial interests.

1. Obeso, J.A., Rodriguez-Oroz, M.C., Stamelou, M. & Bhatia, K. *Lancet* **384**, 523–531 (2014).
2. Calabresi, P., Picconi, B., Tozzi, A., Ghiglieri, V. & Di Filippo, M. *Nat. Neurosci.* **17**, 1022–1030 (2014).
3. Day, M. *et al. Nat. Neurosci.* **9**, 251–259 (2006).
4. Guo, L. *et al. Nat. Neurosci.* **18**, 1299–1309 (2015).
5. Yagishita, S. *et al. Science* **345**, 1616–1620 (2014).
6. Ueno, T. *et al. Neurobiol. Dis.* **64**, 142–149 (2014).
7. Calabresi, P., Ghiglieri, V., Mazzocchetti, P., Corbelli, I., Picconi, B. Levodopa-induced plasticity: a double-edged sword in Parkinson's disease? *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **370**, 20140184 (2015).
8. Weintraub, D., David, A.S., Evans, A.H., Grant, J.E. & Stacy, M. *Mov. Disord.* **30**, 121–127 (2015).
9. Collier, T.J., Kanaan, N.M. & Kordower, J.H. *Nat. Rev. Neurosci.* **12**, 359–366 (2011).
10. Lang, A.E. & Obeso, J.A. *Lancet Neurol.* **3**, 309–316 (2004).
11. Hall, H. *et al. Brain* **137**, 2493–2508 (2014).

Character studies

Ming Hsu & Adrianna C Jenkins

How do individuals attribute dispositional properties, or traits, to others? A study suggests that associative learning processes underlie aspects of trait learning at both neural and behavioral levels.

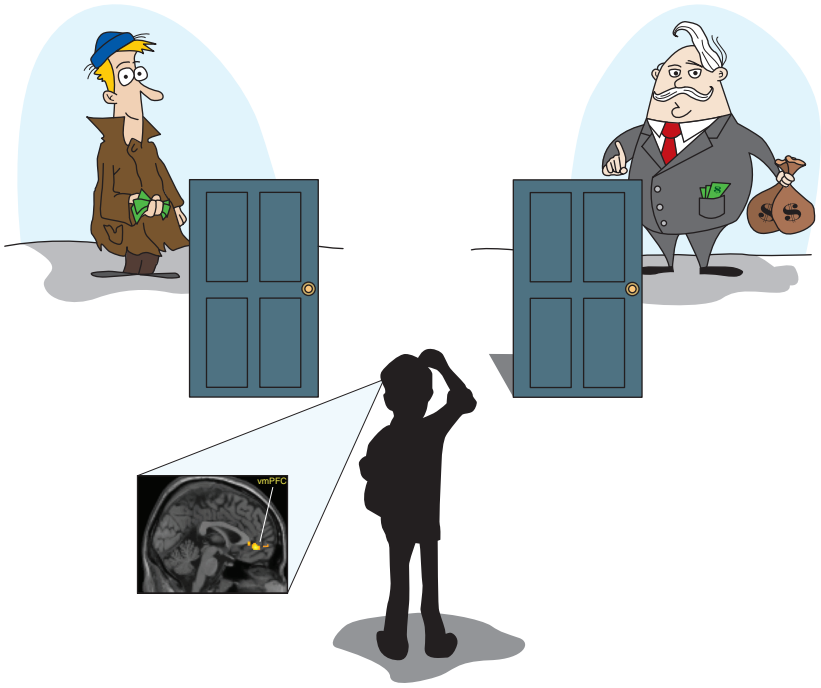
In O. Henry's "The Gift of the Magi", a young wife sells her prized hair to buy her husband a chain for his gold watch, while the husband sells the watch to buy her expensive combs. Thus, unbeknownst to the other, each is left with a gift that neither can use. One possible takeaway is that the gifts failed miserably and that the couple should have consulted each other before their purchases. But most of us focus instead on the husband and wife's generous dispositions.

Beginning with Heider[1], how perceivers attribute dispositional properties, or traits, to others has been among the most enduring questions in psychology[2]. In recent years, there has been increasing interest in approaching this question using cognitive neuroscience techniques. However, despite important advances[3], we remain far from a mechanistic understanding of how particular brain regions enable trait inference, particularly regarding the computations essential to binding high-level theories of social cognition to the underlying neurobiology.

In a functional magnetic resonance imaging (fMRI) study reported in this issue of *Nature Neuroscience*, Hackel, Doll and Amodio[4] take an important step in this direction. Using an innovative combination of ideas and tools from social psychology, economics and cognitive neuroscience, they offer neural evidence that associative learning processes are involved in making inferences about traits. Specifically, the authors conducted a study in which participants interacted repeatedly with eight different partners: four purported human participants and four slot machines. On each trial, participants chose to interact with one of two human (or slot machine) counterparts. The chosen counterpart, who had been endowed with a certain number of points on that trial, then shared some proportion of those points with the participant. Critically, targets varied orthogonally in terms of the average magnitude of their starting endowment (reward) and the average proportion of the endowment that was shared with the participant (generosity), enabling the authors to dissociate signals associated with trait learning from those associated with reward processing.

Consistent with the idea that trait learning engages associative learning processes, BOLD (blood oxygen level-dependent) responses of the

Ming Hsu and Adrianna C. Jenkins are in the Haas School of Business and Helen Wills Neuroscience Institute, University of California, Berkeley, Berkeley, California, USA.
e-mail: mhsu@haas.berkeley.edu



Kim Caesar/Nature Publishing Group

Figure 1 Learning about traits versus rewards. Hackel *et al.*[4] investigated the neural signals associated with trait learning. In an fMRI study, participants interacted with partners who varied in reward (the absolute amount of money shared with the participant) and generosity (the proportion shared). Activity in the ventromedial prefrontal cortex (vmPFC) was associated with preferring more generous targets, even when those targets shared less money in absolute terms. fMRI image reprinted with permission from ref. 4.

ventral striatum during an initial training phase were predicted by an associative learning model that captures both reward and trait information. Moreover, two pieces of evidence support the idea that participants were able to make use of this trait information in a manner described by psychological theories of trait attribution. First, in a test phase in which participants knew each potential partner's starting endowment, participants chose interaction partners on the basis of those partners' past levels of generosity, and the extent to which they did so was associated with activity in the ventromedial prefrontal cortex (**Fig. 1**). In addition, participants exhibited a tendency to generalize these generosity attributions, preferring the more generous targets when asked to pick a collaborator for a new, cooperative task—a hallmark of trait attribution.

At the same time, this study provides evidence that trait learning may also recruit processes not associated with reward learning. Signals associated with traits, but not rewards, were observed in regions previously associated with social cognition, including the precuneus, posterior cingulate and right temporoparietal junction. Intriguingly, these signals were observed for both human and slot machine targets.

As is often the case, the study raises a host of new questions for each one answered. At least two are critical here for advancing our understanding of the neural basis of trait learning. First, to what extent can relatively simple associative processes extend to learning about more complex forms of traits or relationships between traits? The focus of the study was a set of traits defined by specific behaviors and for which participants receive direct and material feedback. Yet trait learning can also take place in settings characterized by sparse or indirect feedback, such as gossip, or by traits that may not be directly observable[5]; for example, anxiousness or optimism.

A second, related question is one of timescale. In particular, associative learning processes can be notoriously slow in convergence[6]. As a result, they would have a great deal of difficulty accounting for the type of one-shot trait inference achieved in "The Gift of the Magi". In both cases, one possible solution is that trait learning in more complex or ambiguous settings relies on internal models used widely in game theory and theories of model-based reinforcement learning[7–9]. Specifically, by allowing trait associations to be guided by internal representations describing how different situations are connected to each other, these models may provide a flexible means through which traits can be influenced by narratives and inferences, in addition to direct experience.

More broadly, the study raises questions about the computational processes supporting social and nonsocial cognition in humans and other animals. First, the observation that trait learning engaged associative mechanisms opens the intriguing possibility of investigating non-human analogs of trait learning in model organisms. Second, the authors observed engagement in a set of brain regions classically associated with considering the minds of people (versus properties of objects)[10] not only when participants learned the traits of humans, but also when they learned those of slot machines.

One possible explanation for this overlap is that participants in the current study anthropomorphized the slot machines, attributing to them the kinds of human-like mental states that they may have attributed to the human targets, such as generous or stingy intentions[11]. Another possibility, favored by Hackel *et al.*[4], is that the cognitive processes in question are not specialized for social cognition *per se*, but are disproportionately relevant to it. Under this view, the engagement of these regions depends less on whether a particular inference involves a human or object than on the extent to which that inference places certain kinds of demands on information processing. Characterizing the nature of those demands and the cognitive processes with which they are met is an especially exciting area for ongoing research.

Recent commentators have noted both the importance and the difficulty of achieving genuine integration across biological and theoretical levels of analysis. As Gary Marcus and colleagues[12] observed, "The challenge for neuroscience is to try to square high-level theories of behavior and cognition with the detailed biology and biophysics of the brain." Hackel *et al.*[4] provide a useful illustration of the rewards that come from combining traits of different research traditions.

COMPETING FINANCIAL INTERESTS
The authors declare no competing financial interests.

1. Heider, F. *The Psychology of Interpersonal Relations* (Wiley, New York, 1958).
2. Gilbert, D.T. in *Handbook of Social Pyschology* (eds. Gilbert, D.T., Fiske, S.T. & Lindsey, G.) 89–150 (1998).
3. Ames, D.L., Fiske, S.T. & Todorov, A. in *The Handbook of Social Neuroscience* (eds. Decety, J. & Cacioppo, J.) 419–433 (Oxford University Press, 2011).
4. Hackel, L.M., Doll, B.B. & Amodio, D. *Nat. Neurosci.* **18**, 1233–1235 (2015).
5. Jenkins, A.C. & Mitchell, J.P. *Cereb. Cortex* **20**, 404–410 (2010).
6. Sutton, R.S. & Barto, A.G. *Reinforcement Learning: an Introduction* (MIT Press, Cambridge, Massachusetts, 1998).
7. Kaelbling, L.P., Littman, M.L. & Moore, A.W. *J. Artif. Intell. Res.* **4**, 237–285 (1996).
8. Gläscher, J., Daw, N., Dayan, P. & O'Doherty, J.P. *Neuron* **66**, 585–595 (2010).
9. Zhu, L., Mathewson, K.E. & Hsu, M. *Proc. Natl. Acad. Sci. USA* **109**, 1419–1424 (2012).
10. Jenkins, A.C. & Mitchell, J.P. in *Social Neuroscience: Towards Understanding the Underpinnings of the Social Mind* (eds. Todorov, A., Fiske, S.T. & Prentice, D.) 3–13 (Oxford University Press, 2011).
11. Epley, N., Waytz, A. & Cacioppo, J.T. *Psychol. Rev.* **114**, 864–886 (2007).
12. Marcus, G., Marblestone, A. & Freeman, J. *Chron. High. Educ.* (http://chronicle.com/article/Mind-Maze/149945/) (12 November 2014).