nonlinear mapping between inputs and the value of possible actions — for instance, the value of a move in each possible direction when playing *Space Invaders* (Fig. 1).

The system picks output actions on the basis of its current estimate of Q^*, thereby exploiting its knowledge of a game's reward structure, and intersperses the predicted best action with random actions to explore uncharted territory. The game then responds with the next game screen and a reward signal equal to the change in the game score. Periodically, the network uses inputs and rewards to update the DQN parameters, attempting to move closer to Q^*. Much thought went into how exactly to do this, given that the agent collects its own training data over time. As such, the data are not independent from a statistical point of view, implying that most of statistical theory does not apply. The authors store past experiences in the system's memory and subsequently re-train on them — a procedure they liken to hippocampal processes during sleep. They also report that the system benefits from randomly permuting these experiences.

There are several interesting aspects of Mnih and colleagues' paper. First, the system performances are comparable to those of a human games tester. Second, the approach displays impressive adaptability. Although each system was trained using data from one game, the prior knowledge that went into the system design was essentially the same for all 49 games; the systems essentially differed only in the data they had been trained on. Finally, the main methods used have been around for several decades, making Mnih and colleagues' engineering feat all the more commendable.

What is responsible for the impressive performance of Mnih and colleagues' system, also reported for another DQN[4]? It may be largely down to improved function approximation using deep networks. Even though the size of the game screens produced by the emulator is reduced by the system to 84 × 84 pixels, the problem's dimensionality is much higher than that of most previous applications of reinforcement learning. Also, Q^* is highly nonlinear, which calls for a rich nonlinear function class to be used as an approximator. This type of approximation can be accurately made only using huge data sets (which the game emulator can produce), state-of-the-art function learning and considerable computing power.

Some fundamental issues remain open, however. Can we mathematically understand reinforcement learning from dependent data, and develop algorithms that provably work? Is it sufficient to learn statistical associations, or do we need to take into account the underlying causal structure, describing, say, which pixels causally influence others? This may help in finding relevant parts of the state space (for example, identifying which sets of pixels form a relevant entity, such as an alien in *Space Invaders*); in avoiding 'superstitious' behaviour, in which statistical associations may be misinterpreted as causal; and in making systems more robust with respect to data-set shifts, such as changes in the behaviours or visual appearance of game characters[3,5,6]. And how should we handle latent learning — the fact that biological systems also learn when no rewards are present? Could this help us to handle cases in which the dimensionality is even higher and the key quantities are hidden in a sea of irrelevant information?

In the early days of AI, beating a professional chess player was held by some to be the gold standard. This has now been achieved, and the target has shifted as we have grown to understand that other problems are much harder for computers, in particular problems involving high dimensionalities and noisy inputs. These are real-world problems, at which biological perception–action systems excel and machine learning outperforms conventional engineering methods. Mnih and colleagues may have chosen the right tools for this job, and a set of video games may be a better model of the real world than chess, at least as far as AI is concerned. ■

Bernhard Schölkopf *is at the Max Planck Institute for Intelligent Systems, 72076 Tübingen, Germany.*
e-mail: bs@tuebingen.mpg.de

1. Mnih, V. *et al. Nature* **518,** 529–533 (2015).
2. Sutton R. S. & Barto A. G. *Reinforcement Learning: An Introduction* (MIT Press, 1998).
3. Watkins, C. J. C. H. *Learning from Delayed Rewards*. PhD thesis, Univ. Cambridge (1989).
4. Guo, X., Singh, S., Lee, H., Lewis, R. L. & Wang, X. *Adv. Neural Inf. Process. Syst.* 27 (2014).
5. Bareinboim, E. & Pearl, J. in *Proc. 25th AAAI Conf. on Artificial Intelligence* 100–108 (2011).
6. Schölkopf, B. *et al.* in *Proc. 29th Int. Conf. on Machine Learning* 1255–1262 (Omnipress, 2012).

BIODIVERSITY

The benefits of traditional knowledge

A study of two Balkan ethnic groups living in close proximity finds that traditional knowledge about local plant resources helps communities to cope with periods of famine, and can promote the conservation of biodiversity.

MANUEL PARDO-DE-SANTAYANA & MANUEL J. MACÍA

Understanding how human groups obtain, manage and perceive their local resources — particularly the plants they use as food and medicine — is crucial for ensuring that those communities can continue to live and benefit from their local ecosystems in a sustainable way. The study of these complex interactions between plants and people is the aim of an integrative discipline known as ethnobotany, which is based on methods derived mainly from botany and anthropology[1]. Most ethnobotanical research reveals that traditional knowledge about local edible and healing resources is suffering an alarming decline[2], especially in Europe[3]. However, writing in *Nature Plants*, Quave and Pieroni[4] suggest that wild plants still have an essential role for communities living in the mountains of Kukës, one of the poorest districts of Albania. Their results also show how preserving local knowledge is linked to maintaining biodiversity.

The mountains of Kukës lie in the Balkans, a hotspot of cultural and biological diversity that has suffered major political and economic shifts over the past three decades. Quave and Pieroni studied two culturally and linguistically distinct rural Islamic ethnic groups (the Gorani and Albanians) that, despite living in close proximity in this region and facing similar environmental and economic conditions, have remained relatively isolated from one another. The two groups use wild plants in different ways, giving the authors an opportunity to investigate the role of cultural factors in shaping how the local flora is understood and used in daily life, health practices and, ultimately, survival. Among the various quantitative techniques used, the authors designed a simple but innovative tool to compare the cultural similarities and differences between the two groups' use of plant species.

The researchers report significant variation in the plant species used for medicinal purposes by the two ethnic groups. A plausible explanation for this is that the spread of health-related lore requires a high degree of affinity, because trying a new remedy requires a great deal of trust[5]. Health is a sensitive topic, so people accept advice mainly from knowledgeable relatives or friends belonging to the same ethnic group[6]. Moreover, many traditional remedies have a highly symbolic component, and the mechanisms by which they are believed to bring about healing can lie — totally or partially — in the remedy's cultural meaning[7].

Quave and Pieroni find only two species,

ROGER SMITH/GETTY

Figure 1 | The dog rose (*Rosa canina*) is used by both Gorani and Albanian ethnic groups.

Urtica dioica and *Rosa canina* (Fig. 1), that were widely used by both ethnic groups, and both species are edible. Generally, there was much more convergence in the food plants used by the two groups. The researchers suggest that this can be explained by the importance of wild edible species in ensuring food security. The robust local lore concerning these plants serves as a reservoir of knowledge, preparing the groups to cope with periods of famine or the scarcity of staple foods[8]. When food is scarce, cultural boundaries seem to be more permeable, because the survival of the group is at stake.

Another issue for consideration is the fact that some species are used medicinally by one group, but sold to plant traders by the other. People assign higher values to species that they use in their daily lives than to those that are harvested for marketing, which, as the authors point out, can have a major effect on the conservation of these resources. The group's relationship with the resource is much more intimate in the former case. Indeed, many regularly used plant species are of great cultural significance and have a prominent place in the local collective memory. They are part of local histories and narratives — they represent the essence, personality and identity of their community.

This study demonstrates that cultural values have a major effect on traditional local knowledge. Sustainable exploitation of local biodiversity is much more likely for resources that are emotionally valued than for those that are used in an impersonal way, as a source of income. A report published last year[9] posited that many indigenous communities that have successfully conserved biodiversity in their locality do so by combining an extensive and experiential knowledge with an intensely respectful emotional engagement with nature. Furthermore, the report suggests that our inclination to conserve biodiversity is a function of the number and intensity of our emotional attachments. Therefore, if traditional local knowledge is forgotten, biodiversity is also in danger of being lost, as is happening in some sacred forests and habitats that are in the process of being transformed and degraded[10].

Studies such as Quave and Pieroni's can help to integrate traditional local knowledge with efforts to conserve biocultural diversity. By focusing on the point of view of people who are or have been deeply dependent on their local resources, these studies can promote culturally appropriate, sustainable development strategies. Unfortunately, this integration has received little support, and the implications of integration are yet to be properly evaluated. Future ethnobotanical studies should build on the innovative approach taken by Quave and Pieroni when testing the role of cultural factors in the distribution and preservation of traditional local knowledge, by comparing the authors' results with larger data sets from informants and communities gathered in other regions worldwide.

Finally, the authors have demonstrated that quantitative techniques for analysing ethnobotanical data can lead to a deeper level of understanding within the discipline. We suggest that quantitative techniques should thus be further explored. Ethnobotany has a key part to play in studies of how ethnic groups can benefit from and coexist with their ecosystems. Policy and decision makers should take into account the views and traditions of local communities, particularly in rural regions with economic and social instability. ■

Manuel Pardo-de-Santayana *and* **Manuel J. Macía** *are in the Departamento de Biología (Botánica), Universidad Autónoma de Madrid, 28049 Madrid, Spain.*
e-mail: manuel.pardo@uam.es

1. Schultes, R. E. & von Reis, S. *Ethnobotany: Evolution of a Discipline* (Chapman & Hall, 1995).
2. Reyes-García, V. *et al. Evol. Hum. Behav.* **34,** 249–257 (2013).
3. Pardo-de-Santayana, M., Pieroni, A. & Puri, R. K. (eds) *Ethnobotany in the New Europe: People, Health and Wild Plant Resources* (Berghahn, 2010).
4. Quave, C. L. & Pieroni, A. *Nature Plants* **1,** 14021 (2015).
5. Cámara-Leret, R., Paniagua-Zambrana, N., Svenning, J.-C., Balslev, H. & Macía, M. J. *J. Ethnopharmacol.* **158,** 58–65 (2014).
6. Menendez-Baceta, G. *et al. J. Ethnopharmacol.* **161,** 116–127 (2015).
7. Moerman, D. E. & Jonas, W. B. *Ann. Intern. Med.* **136,** 471–476 (2002).
8. Johns, T. in *Eating on the Wild Side* (ed. Etkin, N. L.) 46–61 (Univ. Arizona Press, 2000).
9. Hunn, E. *Ethnobiol. Lett.* **5,** 146–150 (2014).
10. Verschuuren, B., Wild, R., McNeely, J. & Oviedo, G. (eds) *Sacred Natural Sites: Conserving Nature & Culture* (Earthscan, 2010).

STEM CELLS

Chasing blood

Many experiments have probed the mechanisms by which transplanted stem cells give rise to all the cell types of the blood, but it emerges that the process is different in unperturbed conditions. **SEE LETTER P.542**

SIDHARTHA GOYAL & PETER W. ZANDSTRA

Blood is one of the most dynamic tissues in the human body, with millions of cells being produced each second. But how blood-cell production occurs under unperturbed conditions, and which stem and progenitor cell types are responsible for stable maintenance of the blood, has been unclear. In this issue, Busch *et al.*[1] (page 542) use a genetic labelling strategy to gain insight into blood-cell production under normal conditions. They reveal that an unexpected subset of blood stem cells is the major player in day-to-day blood-cell production.

Our understanding of haematopoiesis (the process through which all the cells of the blood are generated) is built on experiments in which blood cells are transplanted into recipients whose bone marrow (the source of blood-cell production) has been depleted through a process called myeloablation. The