efficacy [2]. The implicit optimization of neuronal connections (i.e. perceptual learning) leads to hierarchical brain structures (models) that recapitulate causal structure in the sensorium. This optimization process can 'prune' the form or structure of the model (cf., synaptic pruning [5]) and is used routinely in model optimization (e.g. automatic relevance determination [6]). Furthermore, one could regard natural selection as optimizing the structural form of models at an evolutionary scale, through minimizing free-energy (where it is called free-fitness [7]). In a statistical setting, free-energy bounds on model evidence are used routinely in Bayesian model selection (where the log model evidence is negative surprise, e.g. [8];) (Figure 1).

Puzzle: "With the framework providing no principle for deciding the range of ϑ, the brain's representation of the conditional density is inevitably a 'slightly mysterious construct'" [1].

Answer: The range of ϑ (the values it can take) is specified by the form of the (generative) model and the priors it entails. For example, the equation in Box 2 [2] specifies the range of hidden states in the world $x^{(i)} \subset \vartheta$ with the range of a function, for example a neuronal activation function. The 'slightly mysterious' aspect of the recognition density is not its form (nor the implicit range of causes that are represented) but the fact that it is induced by the brain's physical states (which encode the recognition density).

Puzzle: "It is unclear how introduction of the 'free-energy' concept, specifically, adds explanatory content. . .*it is minimization of surprise that is explanatorily salient*" [1].

Answer: The explanatory advance furnished by free-energy is fundamental: it provides a means to minimize surprise. This is because surprise cannot be quantified by an agent, whereas free-energy can. Again, this is not abstract hand waving; the free-energy bound on surprise (or log-evidence for a model) plays an essential role in physics [9], machine learning [10] and statistics [11] for this reason.

References

1 Thornton, C. (2010) Some puzzles relating to the free energy principle: comment on Friston. *Trends Cogn. Sci.* 14, 53–54
2 Friston, K. (2009) The free-energy principle: a rough guide to the brain? *Trends Cogn. Sci.* 13, 293–301
3 Stone, J.V. *et al.* (2009) Where is the light? Bayesian perceptual priors for lighting direction. *Proc. Biol. Sci.* 276, 1797–1804
4 Phillips, C. *et al.* (2005) An empirical Bayesian solution to the source reconstruction problem in EEG. *Neuroimage* 24, 997–1011
5 Tessier, C.R. and Broadie, K. (2009) Activity-dependent modulation of neural circuit synaptic connectivity. *Front. Mol. Neurosci.* 2:8. doi:10.3389/neuro.02.008.2009
6 Tipping, M.E. (2001) Sparse Bayesian learning and the Relevance Vector Machine. *J. Mach. Learning Res.* 1, 211–244
7 Sella, G. and Hirsh, A.E. (2005) The application of statistical physics to evolutionary biology. *Proc. Natl. Acad. Sci. U S A* 102, 9541–9546
8 Daunizeau, J. *et al.* (2009) Variational Bayesian identification and prediction of stochastic nonlinear dynamic causal models. *Physica D.* 238, 2089–2118
9 Weissbach, F. *et al.* (2002) High-order variational perturbation theory for the free energy. *Phys. Rev. E*,66, 036129 DOI: 10.1103/PhysRevE.66.036129
10 Frey, B.J. and Jojic, N. (2005) A comparison of algorithms for inference and learning in probabilistic graphical models. *IEEE Trans. Pattern Anal. Mach. Intell.* 27, 1392–1416
11 Friston, K. *et al.* (2007) Variational free energy and the Laplace approximation. *NeuroImage* 34, 220–234

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Book Review

Dysrationalia: intelligence without rationality

What Intelligence Tests Miss: The Psychology of Rational Thought by Keith Stanovich, Yale University Press, 2009. £16.00 (308 pp.) ISBN 978-0-300-12385-2.

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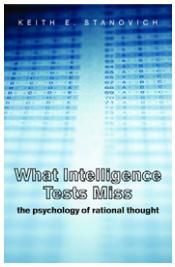

Despite a long tradition of research in both fields, the psychological study of intelligence and its tests has not been well integrated with the psychological study of rationality. Keith Stanovich's well-written and accessible book does integrate these studies and should, for that reason alone, have a highly beneficial impact on both.

Stanovich argues that standard intelligence tests miss the trait than can be of even greater value than relatively high intelligence: rationality. Although these tests measure something of value, it is not rationality: rationality is usually at best modestly correlated with scores on intelligence tests.

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Stanovich relies on the standard view in cognitive science that rationality should be defined in two related ways. It can refer, most fundamentally, to instrumental rationality, which is the ability to achieve one's goals or (more technically) maximize expected utility. It can also refer to epistemic rationality: the capacity to acquire the well-justified beliefs that are usually necessary for goal achievement. Stanovich establishes, both informally and on the basis of an extensive empirical literature, that there is a clear distinction between rationality so defined and intelligence. Intelligence can help to solve some problems about rational belief or action, but is of little help in other cases. An example is *myside bias*, the tendency to evaluate evidence from an egocentric point of view. Stanovich and his collaborator Richard West found no correlation between the magnitude of this bias and intelligence.

Stanovich uses the term *dysrationalia* (on analogy with 'dyslexia') to refer to such 'inability to think and act rationally despite adequate intelligence.' What are the causes of dysrationalia? Intelligent people can be as lazy as anyone else, including being cognitively lazy or, in Stanovich's terms, *cognitive misers*. It is one thing to have the computational power – the IQ – to solve a problem, and another to go to the trouble of using it. To explain in detail how being a cognitive miser can cause problems, Stanovich calls on dual process theory, an account of the mind to which he has made major contributions. As he points out, there is increasing support across psychology – particularly in cognitive and social psychology, judgment and decision making and neuroscience – for a distinction between what he calls Type 1 and Type 2 processes [1,2]. Type 1 processes are often called heuristic: they are fast, automatic, and do not depend on conscious attention or effort. Type 2 processes are slow, controlled, and do depend on attention and effort. It is easy to default to Type 1 heuristic processes. It can be harder to engage in Type 2 processing, which can require the effortful application of normative rules – of logic, probability theory or decision making. Type 1 processing can lead to efficient and reasonably well-justified belief formation and decision making, but also at times to biases and fallacious thought, resulting in unjustified beliefs and failure in goal achievement.

Dysrationalia can also be the result of what Stanovich calls a *mindware gap*. On the one hand, intelligent people can lack the knowledge of logic, probability theory, or the scientific method that is sometimes necessary for the best belief formation and decision making. Their education can be limited or lacking altogether in the relevant normative and scientific theories. On the other hand, some people's education in these disciplines can be so thorough that normative rules become automated and can be applied automatically in Type 1 processing. More generally, at least some Type 2 processing is required for following these rules, but it must not be assumed that Type 2 processing is always normatively correct. Sometimes, indeed, Type 1 heuristics of limited value can be explicitly formulated as rules and cause fallacies in Type 2 processing. It is sadly common, but irrational, for people to continue investing in a hopeless project. They fear 'wasting' their initial investment and thus commit what is known as the *sunk cost fallacy*. If such a 'do not waste' heuristic is overgeneralized in Type 2 processing, it could lead to even more good money being thrown after bad, especially when there is a mindware gap about the fallacy.

There can also be 'education' in what Stanovich calls *contaminated mindware*. Even intelligent people can fall for irrational ideologies, pseudo-sciences, or get-rich-quick schemes. Stanovich reports how over half of Albanian society suffered 'mass dysrationalia' when they were persuaded by confidence tricks to invest in Ponzi schemes (fraudulent investments, where unreasonably high 'returns' are actually paid out of the victims' own capital) that collapsed in 1997. His book was written a little too early to cover the most recent investment scandals in the USA, but these illustrate his points perfectly [3]. Intelligent people invest in Ponzi schemes, or take out mortgages they cannot afford, because they are cognitive misers who trust their gut feelings and do not make relatively simple calculations, or because of missing or contaminated mindware.

Even highly intelligent people can make irrational investments, either as a result of Type 1 heuristic trust in high name recognition on Wall Street or of Type 2 fallacious reasoning. Theoretical views on the usefulness of heuristics have oscillated dramatically. Initial research on heuristics focused on how heuristics could produce biases and fallacies [4]. This approach actually affirmed that heuristics could be useful. However, this conclusion was taken to extremes by a second wave of heuristics research, which stressed only the positive side of heuristics. This second wave of research eventually went so far as to claim that unquestioning reliance on heuristics can be better than knowledge for rationality, and that logic and probability theory are irrelevant for reasoning and decision making [5,6]. Stanovich decisively criticizes the excessive emphasis on the positive side of heuristics, and the recent Ponzi and investment scandals will no doubt help to push the swing back in the other direction.

This outstanding book should stimulate much needed research on dysrationalia and how to measure and correct it. Stanovich, a leading contributor to theoretical research on rationality and intelligence, also has a deep commitment to applying this research to help people become more rational. This comes through strongly in the book, which should be read by everyone with an interest, whether theoretical or applied, in rationality and intelligence.

References

1 Evans, J.St.B.T. (2003) In two minds: Dual process accounts of reasoning. *Trends Cogn. Sci.* 7, 454–459

2 Evans, J.St.B.T. and Frankish, K., eds (2009) *In two minds: dual processes and beyond*, Oxford University Press

3 Greenspan, S. (2009) *Annals of gullibility: why we get duped and how to avoid it*, Praeger Publishers

4 Kahneman, D. *et al.*, eds (1982) *Judgment under uncertainty: heuristics and biases*, Cambridge University Press

5 Todd, P.M. and Gigerenzer, G. (1999) What we have learned (so far). In *Simple heuristics that make us smart* (Gigerenzer, G. *et al.*, eds), pp. 357–366, Oxford University Press

6 Over, D.E. (2000) Book Review: Ecological rationality and heuristics. *Think. Reason.* 6, 182–192

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doi:10.1016/j.tics.2009.11.006 Available online 22 December 2009