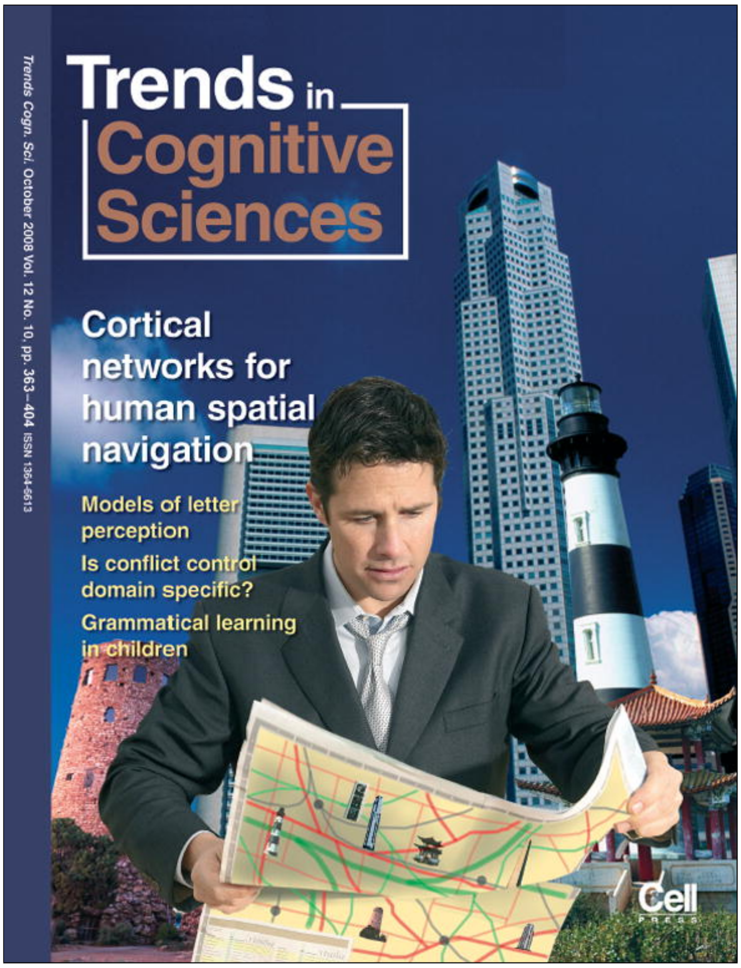
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The knowing visual self

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Like all information-processing systems, biological visual systems are limited by internal and external noise; but this noise never actually impinges on our conscious perception. An article recently published in the *Journal of Vision* suggests that, at least for orientation judgments, the visual system has access to its own noisiness and sets thresholds accordingly. This could well be a general principle in perception, with important and wide ranging consequences.

When light levels are low, photon fluctuations are high, and the retina collects adequate stimulation only sporadically [1], leading to the question: why do we not see photon noise? Why, for example, does the night sky seem to be uniform and not speckled or blobby in such a way as to obscure the stars? Ross and Campbell [2] thought the answer was an increase in the size of receptive fields and a lengthening of visual persistence. They may have been wrong. Morgan, Chubb and Solomon [3] propose another answer, simpler and more general, for this and other cases in which vision is bedeviled by noise (as it always is): vision knows its own noise and sets a threshold to ensure that we do not see it.

Thus, we do not see the blur that is always present in retinal images, nor variation in the orientation of parallel texture elements, although there is variation in their signaled orientation. It is possible – Morgan and colleagues [3] say – that, when we see a texture as uniform, we are not seeing the orientation of every element in the texture but, rather, we see the output of a specialized mechanism that computes orientation variance. If this mechanism were subject to a hard-threshold nonlinearity (or indeed any accelerating nonlinearity) then the perceived uniformity of a uniform texture (or even a non-uniform one) could be explained. As evidence for thresholds, Morgan *et al.* [3] looked for and found a 'dipper' in the psychometric function for increments in orientation variance, a fall followed by a rise in threshold.

Figure 1 illustrates their result. The three panels show an array of grating patches, of average orientation 45° but jittered in orientation by various amounts (0, 2 and 4°). Although the difference in orientation jitter is as great between Figures 1a and 1b as between 1b and 1c (2° in both cases), Figures 1a and 1b look very similar, with all elements apparently aligned, whereas the elements of Figure 1c seem to point in all directions. Morgan *et al.* [3] suggest that there exists a threshold for orientation variance and, if that is not exceeded, the pattern appears in a 'default' condition, all aligned.

The same argument applies to seeing blurred edges as sharp [4], even though our optics and subsequent neural filtering cause inescapable blur. It could also explain why we do not see the image motion caused by incessant low-amplitude eye movements: the visual system seems to estimate their magnitude from visual information and set an appropriate speed threshold [5]. This thresholding principle immediately implies two things: that the visual system, in the absence of evidence to the contrary, opts for clean solutions – sharp edges, unmottled surfaces, 'good' Gestalten; and that it knows its own noise.

Its preference for clean solutions – the 'no porcupines' assumption – is explicable because it has to compute representations of the external world from 2D images that are inherently ambiguous and noisy. It must make regularizing assumptions [6], which are, in effect, Bayesian priors. And, that it does know its own noise, and has a good reason to know, is shown by the fact that when sources of information are combined (e.g. sight with touch or sound) each is weighted according to its precision to give a solution that is Bayesian optimal [7,8].

The sting in the tail of Morgan *et al.*'s [3] proposal is that it implies that what we see is not worked-up versions of retinal images (as Marr's representations are), but things we construct or imagine, from a statistical description of what images contain. We do not see the orientation of each and every Gabor patch on a screen that we look at, but a scatter of orientations (or non-scatter if threshold is not reached) consistent with a variance we compute. This is actually an old idea, tracing back to Helmholtz [9], revived by Gregory as visual hypothesizing [10], but given more bite by the very particularity of what is suggested – a computation of variance and no one-to-one correspondence of orientations in a percept to orientations of objects on a screen.

We have evidence that the apparent number of a collection of things is similarly based on a statistic, and the relationship between the percept and the retinal image is similarly not one-to-one [11]. We had subjects adapt to a large collection of elements, then assess the numerosity of a smaller collection. Estimates fell, by more than half in some cases. Yet when the effects adaptation wore off, and estimates of dot number returned to normal, none of the dots seemed to have reappeared or to have been missing. We think this provides a clear answer to a philosophical conundrum, the problem of the speckled hen, more than 60 years old but still the subject of controversy [12]: does a single glance at a speckled hen provide us with a sense

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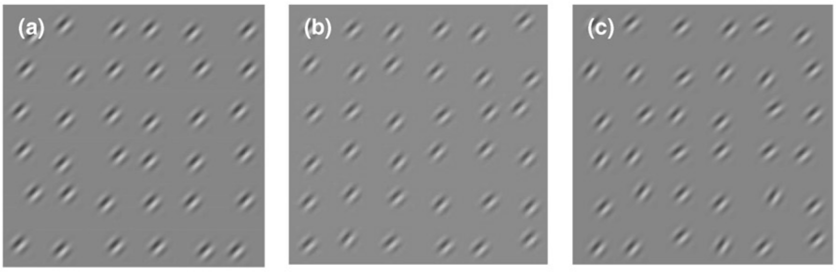

Figure 1. Examples of the stimuli used by Morgan *et al.* [3]. The elements are 'Gabor patches', sinusoidal gratings vignetted within a Gaussian window, laid out in a pseudo random manner. The orientation of each element is 45+G(σ)°, where G is a pseudo random number obtained from a Gaussian distribution of mean 0 and standard deviation 1, and σ is equal to 0°, 2° and 4° in (**a**), (**b**) and (**c**), respectively.

datum (percept) containing a definite number of speckles? No, we would say, because that is not how perception works.

Acknowledgements
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Book Review

Two complementary perspectives on synaesthesia

The Hidden Sense: Synesthesia in Art and Science by Cretien van Campen, The MIT Press, 2008. US$29.95, hbk (185 pp.) ISBN 978-0-262-22081-1

The Frog who Croaked Blue: Synesthesia and the Mixing of the Senses by Jamie Ward, Routledge, 2008. US$16.69, pbk (174 pp.) ISBN 978-0-451-43014-2

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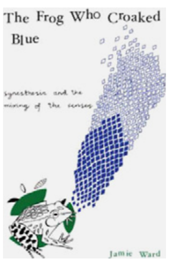
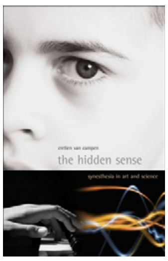


The Hidden Sense by Cretien Van Campen and *The Frog Who Croaked Blue* by Jamie Ward are the latest instalments in a rapidly growing series of scientific and popular writings on a fascinating condition known as synaesthesia. People with synaesthesia experience a melding of the senses in which ordinary everyday stimuli trigger conscious experiences that most people do not associate with those stimuli [1]. For instance, sounds can elicit experiences of colour (e.g. a frog's



croak is blue), tastes can lead to tactile sensations and units of time (e.g. months, days and years) are seen as occupying spatial locations outside of the body.

The two books by Van Campen and Ward provide distinct yet complementary insights into synaesthesia. Van Campen, a social scientist, considers the relation between synaesthesia, science, art and culture. In tackling such a diverse range of topics, he inevitably transcends the available empirical evidence, yet his conclusions still provide valuable lessons for scientists and laypersons alike. Van Campen provides a

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