To evaluate these models, the authors reported three experiments with college students, as well as previously published data from amnesic patients [3]. Results decisively precluded the possibility of independent systems. Even within 'old' and 'new' items, identification times were faster for words called 'old' versus words called 'new', for words recognized with a high versus a low level of confidence, and for words that participants claimed to consciously recollect versus words they claimed were merely familiar. Even amnesic patients showed numerical evidence of these effects. As the independent-systems model has no mechanism for producing this link, it must be rejected in favor of either the single-system model or the overlapping-systems model. The single-system model was often preferred by fit statistics that penalize for the number of model parameters (Akaike information criterion). However, one of the amnesic patients showed detectable priming with no discrimination on the recognition task, a result that is not possible under the single-system model.

Although Berry *et al.* [2] tested only one form of implicit memory and tests of others are needed (e.g., word fragment completion), their results are an important first step in simultaneously modeling implicit and explicit memory. Nevertheless, their work leaves ample room for further theoretical development. One important direction is to distinguish the single-system model from the overlapping-systems model with targeted manipulations that qualitatively (not just quantitatively) support one model and reject the other. A second important direction is to specify how the values of memory strength that drive identification and recognition are produced (i.e., develop a process model, [4,5]). Still another critical advance would be to develop a more realistic model of response times by moving to a sequential sampling decision model [6–9]. In their current form, the models suggested by Berry *et al.* do not address response times for recognition decisions and the simplistic linear function they use to map strength onto identification times cannot accommodate full response time distributions across a range of experimental variables and tasks. In many applications, models that can explain only accuracy or mean decision times have been profitably replaced with models that can explain both accuracy and full response time distributions (see [7] for a review).

The Berry *et al.* [2] article highlights two important messages that should influence the future of research on implicit and explicit memory. First, even if implicit and explicit memory can be dissociated in special situations, Berry *et al.*'s results demonstrate a profound overlap in the memory processes involved in priming and explicit recognition. This overlap should be accommodated theoretically (see the discussion in [10], p. 405). Second, Berry *et al.* show that future progress requires a more rigorous formal approach to theory than has previously characterized this domain. A modeling approach should direct attention away from simply establishing how many systems we can differentiate and toward a more important question: how do these systems work and how do they work together?

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1364-6613/$ – see front matter
doi:10.1016/j.tics.2012.02.005 Trends in Cognitive Sciences, April 2012, Vol. 16, No. 4

Number, texture and crowding

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A recent study shows that selectivity for numerosity emerges as a natural property in deep networks of hierarchical generative models of visual perception. These results, together with recent conceptualizations of crowding and texture, suggest that the 'sense of number' is a fundamental visual property, independent of texture and seemingly related attributes.

Most adult humans can count. However, we also share an approximate non-verbal system with infants and other animals: a visual 'sense of number' [1]. We can visually estimate the numerosity of sets of items, with a margin of error which increases with set size, following 'Weber's law' (like most perceptual processes). Neurons tuned for number have been found in the higher reaches of the visual system of non-human primates [2]. Moreover, numerosity, like all primary sensory properties, is susceptible to adaptation: prolonged exposure to a more numerous visual stimulus makes the current stimulus appear less numerous and vice versa [3].

Surprisingly, there has been considerable resistance to the idea that number could be a visual attribute. Several

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authors question whether numerosity could be sensed directly, insisting that it could only derive indirectly from texture density [4,5], which is also subject to adaptation [6].

A new study provides strong support for the number sense and shows how it could develop naturally within visual neural structures, independently from texture perception. In an article published in *Nature Neuroscience,* Stoianov and Zorzi [7] show that selectivity to visual numerosity emerges naturally during unsupervised learning of a hierarchical generative model of perception. The learning concerned only the efficient coding of the sensory data, yet numerosity selectivity emerged as a statistical property of the deepest layer of the model. The units of these layers discriminate number in a way similar to humans: they obey Weber's law (with a Weber fraction of 0.15, similar to humans), they are invariant to area, density and object features, and selective to a limited region of space. Interestingly, a separate coding emerges for density and number. The properties of these units are not only consistent with human psychophysics, but also with the properties of lateral intraparietal (LIP) neurons in the monkey [8]. That these properties should emerge naturally and incidentally to the primary reinforcer of learning (success in reconstructing the input) strongly supports the notion that number is a primary visual attribute or *quale*.

Concurrently with the recent flurry of work on number estimation, researchers are making strides in understanding crowding: the difficulty in reading packed text with peripheral vision [9,10]. The general conclusion arising from this work is that crowding occurs when features of one or more objects encroach on the receptive field in which the object of interest (e.g. a letter) falls. The object then is difficult or impossible to see, and becomes part of a texture. As Pelli and Tillman succinctly explain, texture is what we see when object recognition fails [10]. This is probably the most accurate and compact definition of texture available. The balls on a snooker table, like the spots commonly used in experiments on number estimation, do not form a texture, since each is easily recognized as an object. The nap of the cloth on a billiard table is a texture, as is sandpaper or the fur of a cat.

The insight arising from this work is that texture is no basis from which to derive number. When object recognition fails, it is impossible to count objects or to estimate their number.

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