nature

NEWS & VIEWS

LANGUAGE

Startling starlings

Gary F. Marcus

Recursion, once thought to be the unique province of human language, now seems to be within the ken of a common songbird — perhaps providing insight into the origins of language.

Man the tool-maker. Man the cultural animal. Man the mimic. It's tempting to summarize the differences between humans and other species in a concise phrase, but most posited differences have turned out to be overstated. Chimpanzees and gorillas use sticks to fish for termites; orangutans use sticks for autoeroticism. And many of these capacities seem to be culturally mediated; they are transferred from one primate to the next by illustration and observation, rather than learned afresh by trial and error[1].

The report by Timothy Gentner and colleagues on page 1204 of this issue[2] challenges one more putatively uniquely human adaptation: the capacity to recognize complex 'recursive' structure. Gentner *et al*. showed that at least one non-human species, the European starling (Fig. 1), can be trained to acquire complex recursive grammars such as the A^nB^n language (in the case of the starling, *rattle rattle warble warble*; see below).

Recursion, or self-embedding, is without question a hallmark of human language. For example, one can take a phrase such as *love conquers all* and embed it in a frame such as *X knows Y*, yielding, say, *Chris knows love conquers all*. The output of that process can then be fed back into the *X knows Y* frame, yielding, say, *Terry knows Chris knows love conquers all*. Embedding also makes relative clauses possible, as in the bracketed part of *the paperback [on the coffee table] is hilarious*. Marc Hauser, Noam Chomsky and Tecumseh Fitch[3] have speculated that recursion might be unique to humans — and perhaps even the only contribution to language that is human-specific. Consistent with this, Fitch and Hauser[4] found that cotton-top tamarin monkeys could not distinguish the A^nB^n language from an ostensibly similar language $(AB)^n$ that need not be constructed recursively.

The A^nB^n language (see Fig. 1 of the paper[2] on page 1204) is generally assumed to be recursive because new sentences can be formed by successive insertion into the frame *AXB*, for example *AB*, *AABB*, *AAABBB* and so on. Gentner and colleagues[2] rewarded European starlings for pressing a bar in response to A^nB^n strings of starling-generated sounds, such as *rattle rattle warble warble*, and withheld the reward for responses to the $(AB)^n$ grammar (and vice versa for another group of starlings). Although learning was not instantaneous, nine of eleven birds eventually (after 10,000–50,000 trials) learned to discriminate reliably between the two grammars, succeeding where the monkeys had failed. An extensive series of control comparisons strongly suggests that the ultimately acquired grammar is robust. Notwithstanding some minor worries[5], this is strong evidence that humans are not alone in their capacity to recognize recursion.

What explains the discrepancy between the starlings' success and the tamarins' apparent failure? One possibility is methodological: Fitch and Hauser[4] tested whether tamarins could acquire A^nB^n spontaneously from a relatively brief exposure, whereas Gentner *et al*.[2] asked whether starlings could acquire similar structures from considerably longer exposures, enhanced with positive feedback, in a more active task. Only further experimentation can clarify whether tamarins' apparent inability to recognize the A^nB^n structure is context-specific or genuinely absolute.

If the split between tamarins and starlings does prove robust, further comparative work will clearly be necessary. Can other varieties of birds that don't (in contrast to starlings) naturally acquire new songs also acquire self-embedded structures? Are humans alone among primates in their capacity to do so? Might the capacity for recursion be general across great apes, even if it were absent in monkeys? An intriguing possibility is that the capacity to recognize recursion might be found only in species that can acquire new patterns of vocalization, for example songbirds, humans and perhaps some cetaceans.

Whether or not tamarins can be prodded


D. D. BALECKAITIS

Figure 1 | No bird brain. The European starling, *Sturnus vulgaris*, which Gentner *et al*.[2] show is capable of recognizing complex grammar.

into recognizing recursion, the analogous human capacity seems robust. Humans are quick to notice recursion and are able to do so without explicit reinforcement; perhaps most importantly, they can generalize recursive structures broadly. Starlings have thus far been shown to be able to extend A^nB^n only to new sequences of familiar sounds. Humans can clearly go further; once you recognize the pattern in *AABB* and *AAABBB*, it is a trivial matter to extend that pattern to new vocabulary (for example, *CCCDDD* or *JJJKKK*). Taken together with the tamarins, there actually seems to be a three-way split: some species may generalize recursion only to items that have already been instantiated in a given pattern; some species can generalize recursion freely to newly acquired vocabularies (arguably the essence of human language); and some species apparently cannot recognize recursion at all.

The "abstract computational capacity of language"[3] may consist not so much of a single innovation as a novel evolutionary reconfiguration of many (perhaps subtly[6] or even qualitatively[7] modified) ancestral cognitive components, genetically rejigged into a new whole. Contemporary research suggests that the human brain contains few if any unique neuronal types, and few if any genes lack a significant ancestral precedent[8]. At the same time, humans show much continuity with their non-speaking cousins in dozens of ways that might contribute to language, including mechanisms for representing time and space, for analysing sequences, for auditory analysis, for inhibiting inappropriate action, and for memory.

None of this challenges Chomsky's long-held conjecture[9] that children are innately endowed with a universal grammar — a set of mental machinery that would lead all human languages to have a similar abstract character. But that shared abstract character may have as much to do with our lineage as vertebrates as with our uniquely human innovations. In Charles Darwin's immortal words, "throughout nature almost every part of each living being has probably served, in a slightly modified condition" in some ancestor or another. ■

Gary F. Marcus is in the Department of Psychology, New York University, 6 Washington Place, New York, New York 10012, USA.
e-mail: gary.marcus@nyu.edu

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SUPERCONDUCTIVITY

Quantum stripe search

Jan Zaanen

Do quantum stripes exist or not? Further indirect evidence for this controversial behaviour of electrons in high-temperature superconductors comes from measurements of atomic-lattice vibrations.

Since 1995, the 'stripe wars' have been raging in the demesne of high-temperature superconductivity. This fierce conflict, fought with the highest-calibre weapons of experimental physics, has its antecedent in a hotly contested claim about the way electrons behave in the copper oxide materials notoriously used as high-temperature superconductors. Supposedly, they form highly organized patterns called quantum stripes — but only on the picosecond timescale, so the patterns average away over longer periods through the electrons' constant quantum dance.

The dispute has lasted so long only because it has proved very hard to nail down such genuine quantum behaviour. In this issue, however, Reznik *et al.* (page 1170)[1] present further evidence in support of quantum stripes. They show that the collective vibrations of the atomic lattice of certain superconducting copper oxides behave in a manner that is hard to explain — unless one assumes that motions characteristic of the presence of quantum stripes are shaking the ion lattice. So is the end of hostilities in sight?

It is an everyday experience that, in a many-body system, collective behaviours emerge that are utterly unrelated to the behaviours of the objects that make it up. The evolution of a nation's economy over time, for example, is difficult to predict from the often conflicting motivations of the constituent human members. The same principles apply in quantum physics. But the exact rules that govern quantum emergence are poorly understood; uncovering them is a core business of modern physics.

Conventional superconductors — those operating only at temperatures very close to absolute zero — demonstrate only a minimal form of quantum emergence. In such materials, interactions between electrons diminish at low temperature, and the macroscopic electron system turns into a near-ideal (non-interacting) quantum gas of 'quasi'-electrons. A small residual attractive interaction binds these quasi-electrons in pairs, which in turn collapse to a single quantum state in the process known as Bose–Einstein condensation.

Although this theory of superconductivity, known as the Bardeen–Cooper–Schrieffer (BCS) model, gets everything right for conventional superconductors, it explains hardly anything in high-temperature superconductors. The discovery 20 years ago of this unusually sturdy form of superconductivity raised the curtain on a drama of wider relevance: the huge numbers of strongly interacting electrons in the copper oxide layers were plainly showing an unknown kind of collective quantum physics (for an overview, see ref. 2). In 1995, it was discovered[3] that small changes in the crystal structure of high-temperature superconductors can cause superconductivity to disappear, with a peculiar 'static stripe phase' taking over (Fig. 1). Here, strong interactions and quantum motions work together to form patterns of electrons moving in serried ranks. Domains in which the electrons come to a complete standstill separate these 'rivers of charge' (Fig. 1b).

The existence of static stripes, initially contentious, is now generally accepted. But quantum stripes are more radical and controversial. Members of the quantum-stripe faction hold that stripes are, in fact, always present. When a material superconducts, the stripes do not disappear; rather, a quantum-mechanical superposition of countless disordered stripe states forms (Fig. 1a), in such a way that the overall state corresponds to that of a superconducting quantum liquid (for a mathematical proof of principle, see ref. 4).

So how can we nail down quantum stripes experimentally? Consider Erwin Schrödinger's oft-cited cat hidden in a sealed box (Fig. 1c). Classically, the cat must be either dead or alive, but quantum mechanically it is in a superposition of dead and alive states. In the quantum state, the cat fluctuates back and forth between alive and dead states. This fluctuation takes a finite time. So, by taking snapshots quickly enough, one can see either a dead or a live cat. The same scheme works equally well with superpositions of countless many-electron configurations. Here, every quantum configuration takes the role of a classical 'dead or alive' state (Fig. 1c).

The fluctuation time of the quantum stripes is in the picosecond (10^{-12} second) range, and the problem for the experimentalist is how to grab a picture of complicated spatial electron patterns in so little time. One way to do this is to observe the change in kinetic energy of neutrons that scatter off the material inelastically. Since 1995, such neutron-scattering experiments have added to the body of evidence supporting the case for quantum stripes[5]. The drawback is that these studies relied on information about the direction of the electron spins that was open to alternative interpretations, including some compatible with the conventional BCS picture (see ref. 6 and references