COMMENTARY

Cultural evolution and the way we count

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A few years ago on the Pacific Island of Tonga, I stood a few yards distant from a little shed as Feinga explained to me what he did with the many yams from his garden (Fig. 1). Yams, a highly desired food in much of Oceania, are often at the center of village events today as they were in the past. In 1777, explorer Captain James Cook witnessed the *'inasi* ceremony, or annual tribute presentations, where yams and other food were presented to the chiefs of Tonga. There, as in other parts across Polynesia, tributes to ruling elites and trading between islands involved managing large quantities of food, requiring numerical operations such as addition, multiplication, and division of these resources both within and between islands. As an important management tool, the system to count these quantities arose and was maintained through cumulative social learning and innovation, a prime example of Darwinian evolution. Over the last decade, our evolutionary understanding of cultural complexity and dynamics has significantly increased as empirical studies (1–3) address the mathematical theory laid out in the 1980s (4, 5). Among key questions are how new cultural variation is introduced, and what advantages enable a cultural variant to become common in society. In PNAS Bender and Beller (6) address these two questions, detailing the innovative manner in which a small Pacific Island population represented quantities, or how they counted, before European contact.

The way we count and the ability to count accurately has evolutionary consequences that likely drove the ability for arithmetic in the animal world to become common (7). Counting and comparing the number of predators or the amount of food, for example, has direct implications for survival and reproduction. However, our cognitive abilities quickly reach a limit. Part of the challenge involved in making accurate numerical comparisons lies in what is called the "distance and magnitude effect." If we imagine separate piles of yams from Feinga's garden (Fig. 1), the closer the quantities and the larger the quantities to compare, the harder it is to distinguish which pile has more yams. Humans and nonhumans alike are subject to these challenges, but otherwise have impressive abilities for approximate calculations (7). For greater precision, culture is required to produce more complex systems of measurement, number representations, calculations, and abstract representations.

Fig. 1. Feinga's yams and other garden products. Large quantities of these and other resources were part of the tribute and trade systems of Pacific Island societies.

Perhaps because of the right cognitive machinery at the right time (8), humans evolved the evolution of complex culture, leading to sophisticated numbering systems. Only the chimpanzee has shown the ability for symbolic addition after extensive training (9). On the other hand, a young human child can effortlessly gain the ability of extensively trained adult chimps. What benefits do culturally evolved systems of counting give humans, and how do they arise? Bender and Beller (6) show how two distinct counting systems, the decimal and the binary, were combined to create an effective measurement system on the Pacific Island of Mangareva.

The decimal system, as is used by most people today, relies on 10 symbols (0–9) that can be combined to represent larger quantities. Operations in the decimal system require memorizing rules or facts for manipulating the 10 symbols, yielding a compact representation of even very large numbers. In contrast, the binary system relies on the presence or absence of two symbols, 0 and 1, with representations of larger numbers marked by a 1 at each position: for example, 1011_2. Each position toward the left increases in a level of power that can be combined to represent a larger quantity, here translated to the decimal system: $1011_2 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 = 11$. Obviously, the decimal representation, 11, is far more compact. However, addition and multiplication in the binary system only requires knowing how the representation is incremented for two symbols. No multiplication or addition tables required!

It is this latter advantage of the binary system that Bender and Beller (6) argue prompted the Mangarevans to mix a

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See companion article on page 1322.

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binary-type system with the dominant decimal system found in Polynesia. The authors describe the Mangarevan terms for the different levels of power and demonstrate how they are combined with the terms of the decimal system. The authors then show, noting important assumptions, how salient operations to island societies—addition, multiplication, and division—may be accurately conducted with the mixed representation. Throughout, Bender and Beller assume that the fewer rules translate into a significantly less cognitive effort when conducting operations necessitated by the Mangarevan socio-ecological context.

Bender and Beller's (6) findings are intriguing, begging many questions regarding the evolution of this system. Feinga, as well as the Pacific Islanders of Captain Cook's day, used the decimal system for counting items, and it was likely the system brought by the first colonizers of eastern Oceania beginning 3,000+ y ago. Thus, Bender and Beller argue the observed mixed system of decimal and binary representations was invented independently in Mangareva, for the advantages just described. It is fair to argue that number systems would not evolve if they didn't have some use. Specialists whose job it is to keep an account of tribute and the nature of relations are the likely suspects to maintain the system, although the common person, in hierarchical Polynesia, will need to have some knowledge of the system for it to work.

However, if the mixed system had an advantage for managing trade or tribute across groups, and presumably Mangareva was part of a large trade network, why didn't it spread more broadly across neighboring islands? Was it relegated solely to internal affairs? Similarly, why was it invented only on Mangareva, and not the other islands of the Pacific with similar ecologies? These puzzles beg a more sophisticated treatment of how the Mangarevan mixed system became established through the process of learning and diffusion (10). For example, we can imagine counting systems as a coordination game, where conforming with another's way of counting yields higher rewards. Try convincing those around you to stop counting eggs in dozens, but to do so in tens. Successful? Probably not. So even if a powerful chief coerced an island to adopt a new way to count, this dynamic may have prevented other islands in the trade network from doing the same.

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As Bender and Beller note (6), directly answering some of these inquiries is nigh impossible for the Mangarevan case. In many parts of the Pacific, European contact quickly transformed indigenous knowledge and social systems that often sustained this knowledge before they could be studied in depth. However, these questions can be indirectly addressed through comparative naturalistic studies or carefully designed experiments. To Bender and Beller's credit, they perhaps uncovered a model system for studying cultural evolution, and present us with some interesting hypotheses to be evaluated by future work. Grasping cultural variation and complexity not only requires understanding the advantages to variants, but also the social influences that spread or deny them. Why did only Mangareva have this innovative counting system and others did not? I look forward to what Bender, Beller, and others in this field uncover.

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