But suppose our atom has a pair of excited states as in panel B. There it is seen that the excited states a_1 and a_2 couple with the ground state b, yielding two dipole currents, one associated with the $a_1 \leftrightarrow b$ transition (antenna 1) and one with the $a_2 \leftrightarrow b$ transition (antenna 2). Excited individually, both states a_1 and a_2 decay as their atomic currents radiate energy. However, when the atomic radiators 1 and 2 have the same frequencies (as is the case when states a_1 and a_2 have the same energies) and the atomic currents 1 and 2 are 180° out of phase, then the emitted radiation fields cancel. Thus, the atom remains excited because the electromagnetic field carries away no energy. In other words, the currents in antennas 1 and 2 cancel, and the atom is "locked" in the superposition of equal energy states a_1 and a_2 (*8*).

But now the plot thickens. Under some conditions, even when the energies of the a_1 and a_2 states are not equal (and the dipole currents 1 and 2 have different frequencies), the atom can still be locked in an excited state a_1, a_2 doublet. For example, we found some time ago (*4*) that when an atom is properly prepared and placed in a cavity as in panel C, it can be locked in an excited state doublet. This example is a harbinger of the present studies. We now know that even in free space, the driven atom of panel D can yield two dipole currents having the same frequency and oscillating 180° out of phase. For example, when the a_1, a_2 pair is driven by a laser coupling the pair to another state (c), as on the right side of panel D, we find antennas 1 and 2 can oscillate at the same frequency.

The interesting point is that the antennas 1 and 2 corresponding to the $a_1 \leftrightarrow b$ and $a_2 \leftrightarrow b$ transitions can oscillate at the same frequency when levels a_1 and a_2 are coherently coupled or driven to some fourth level (c in panel D). Even if we inject the atom in state a_1 only, the laser field will force the atom (partially) into an "anti–phased-antenna" configuration and the atom will remain (partially) excited.

An experiment was carried out in molecular sodium (*9*), which supports the theoretical predictions. Furthermore, recent work of Paspalakis and Knight (*10*) has shown that it is possible to use two driving fields to quench spontaneous emission. The advantage of the two-field approach is that it allows us to control spontaneous emission by changing the relative phase between the two fields. Further work (*11*) has shown that it is possible to view the problem from the perspective of a special dressed state prepared by the laser and resulting in states a_1 and a_2 acquiring equal energy components.

This quenching of spontaneous emission by quantum coherence provides yet another example of counterintuitive quantum effects. Might there be further surprises in store? Probably. Zhou and Swain (*12*), have shown that the present ideas can sharpen spectral lines and is potentially of interest as a spectroscopic tool. Looking further ahead, we might ask if we can hope to enhance lifetimes in complex molecules? Perhaps, time will tell.

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PERSPECTIVES: EVOLUTION

Ants, Crops, and History

Jared Diamond

Human agriculture, which arose around 10,000 years ago in the Fertile Crescent and China, was anticipated about 50 million years ago by fungus-growing New World ants of the tribe Attini that includes the famous leaf cutters (*1*). Ant agriculture is highly specialized. The ant farmers grow fungi in their nests, add manure to stimulate fungal growth, eliminate competing weeds mechanically and by use of antibiotic herbicides so as to maintain a monoculture of the desired crop, and finally consume fungal parts. Ant farmers have lost their own digestive enzymes, relying instead on fungal enzymes to produce low molecular weight absorbable nutrients.

Ant agriculture raises many unsolved questions, with obvious parallels to human agriculture. But progress on these questions for ants has been impeded by uncertainty as to the relationships and wild ancestors of ant crops. On page 2034 of this issue, Mueller *et al.* (*2*) describe a vigorous molecular genetic attack on these questions. They screened 862 fungi (553 ant crops and 309 related wild mushrooms) by restriction fragment length polymorphisms, then sequenced two genes from 57 of the crops and 27 of the mushrooms. In effect, they begin to assemble the type of information on ants already abundantly available from decades of research on humanity's crops and domestic animals (*3–5*). Several conclusions emerge from a comparision of ants and human farmers.

All ant farmers propagate their fungal crops vegetatively (asexually) as clones. Humans do so for some crops, such as bananas, but most of our crops and all livestock (until Dolly) are grown by sexual reproduction from seeds or pregnancies. Moreover, any given ant "village" (nest) cultivates only a single crop (fungal clone), which nevertheless supplies much or most of the ants' nutrition. In contrast, most human farming villages cultivate many different crops; those that cultivate monocultures rely on trade to obtain other cultivars for nutritional balance. The closest human parallels to ant monocultivators are some Old World arid-environment herders heavily reliant on a single domestic animal (horse or camel) without crops.

Molecular evidence indicates at least five clades of ant fungi, attesting to at least five independent domestication events, rather than the single event previously thought possible. Almost all of those fungal crops belong to a single tribe of fungi, the Leucocoprini. Human herds are only slightly more diverse: only 14 significant species of large mammalian domestic herbivores worldwide, and originally only one species in the Americas, six in East Asia, and seven in West Eurasia (*6*). But human farmers have domesticated hundreds of crops belonging to very different groups, ranging from cereals and legumes to root crops and nut trees.

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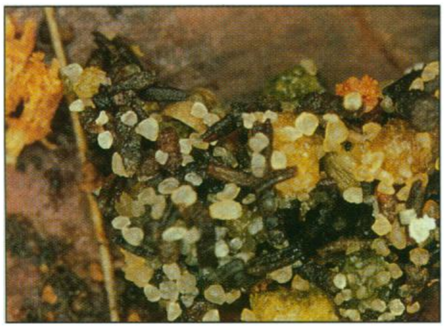


Yeast garden of the ant *Cyphomyrmex*.

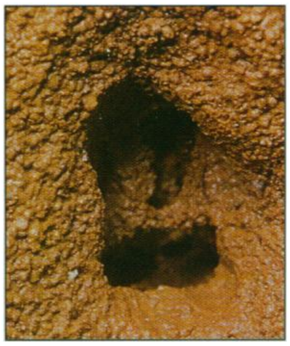
Although a given ant nest contains only one crop, different nests of the same ant species usually alternate between at least two, in one case up to eight, different crops. There is even more variation in the crops on which different farms of the same human society specialize, as can be appreciated from the dozens of different fruits and vegetables sold at a local Farmers' Market and all grown within 100 miles.

Mueller *et al.* identified seven cases in which the same crop is shared among different ant species of the same genus, and four more cases involving ant species belonging to different genera. Such sharing of domesticates among different human societies is the rule; for instance, even before the European overseas expansion that began in A.D. 1492, maize was widespread among Native American societies of both North America and South America, and wheat and horses were widespread among Old World societies.

Some of that crop sharing among ants results from lateral transfer of the same crop clone between ant species. For example, one ant species introduced into Florida in the 20th century has already acquired a crop cultivated by an indigenous Florida ant species. Such sharing develops when one ant species borrows a crop from another's nest, or when several nests become disturbed and mixed. Lateral transfer of crops is ubiquitous among modern humans. A typical McDonald's restaurant meal includes foods based on beef, chicken, potatoes, and kola nut (Coca Cola), originating from the Fertile Crescent, China, Andes, and tropical West Africa, respectively. Our lateral transfers were widespread even before 1492, extreme examples being the pre-Columbian transfers of Andean sweet potatoes to Polynesia and of Asian bananas and rice to East Africa.

Nevertheless, some ant sharing of crops apparently arose through multiple independent domestications of the same wild fungal clade. Among human farmers, multiple independent domestications were common in the Americas (such as squashes, tobaccos, cottons, and beans), where the continents' north-south major axis impeded lateral transfer, but uncommon in Eurasia because of rapid lateral transfer along an east-west axis (exceptions being the repeated independent domestications of pigs and cows) (*6*).

Mueller *et al.* identified two cases of ant fungal crops identical or nearly identical to wild-growing mushrooms. They interpret these cases as evidence for ongoing recent domestications of wild fungi, rather than escapes of cultivated fungi to the wild. In contrast, humans have largely ceased re-domesticating valuable crops from the wild, even though wild ancestral populations still exist for many of our crops. Most wild populations of our domestic animals, such as wild dogs and horses and cattle, represent feral escapees.



Entrance to the fungus farmers' nest.

Clearly Mueller *et al.* have opened rather than exhausted an interesting area. I cannot resist mentioning three tantalizing directions for future work. First, their methods could be applied, by straightforward lateral transfer, to studying the crops of the Old World's fungus-growing termites, which are evolutionary parallels to the New World's fungus-growing ants. Second, modifications of our own crops and livestock under artificial selection by farmers are so obvious that Darwin devoted the entire opening chapter of his *Origin of Species* to the subject. Corresponding modifications of the ant fungal crops are (surprisingly at least to me) not obvious, even though the ants themselves have evolved obvious modifications. As Mueller *et al.* note, chemical modifications of the fungi to match olfactory and gustatory capabilities of ants are a promising area to begin to look. Finally, since the rise of agriculture, human farmers have also "domesticated" the specialized human pathogens responsible for our crowd epidemic diseases and mostly derived from similar pathogens of the domestic animals with which farmers live closely (*6*). Human measles, tuberculosis, and flu evolved from pathogens of cattle, cattle, and pigs, respectively. What might sequencing of the smallpox virus and of syphilis treponema, and of their potential "wild ancestors" among domestic animal pathogens, reveal about the likely time and place of origin of these diseases that played so large a role in human history?

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PERSPECTIVES: NEUROSCIENCE

The Saturation Debate

T. V. P. Bliss

Here's a question often debated in the examination halls and coffee rooms of neuroscience and psychology departments during the last two decades: Does long-term potentiation (LTP)—the enduring enhancement of synaptic efficacy triggered by bursts of high-frequency stimulation—provide the cellular basis for hippocampal-dependent behavioral learning? Or, to be more succinct, does LTP = learning? The question is easily posed, but—as might be expected of an issue lying at the boundary of the physiological and the cognitive—an unequivocal answer is proving remarkably elusive. On page 2038 of this issue, Moser and colleagues (*1*) revisit the problem by using an approach first attempted around 10 years ago in the laboratory of McNaughton and Barnes (*2*, *3*).

If learning is the result of changes in synaptic weight, then blocking such changes should impair hippocampal-dependent learning. One way to achieve this would be to drive all synapses to their maximum efficacy—in other words, to use LTP itself to block the potential for further change. McNaughton *et al.* implanted recording electrodes bilaterally in the dentate gyrus of the hippocampal formation in rats, and using single bilateral stimulating electrodes delivered multiple episodes of tetanic stimulation to axons of the perforant path (the fiber tract that is the principal input to the dentate gyrus) until LTP was saturated. When they trained

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