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Yearning to be Round:

A Primer in Ecological Concepts in 16 Parts

11. All Lives Interlive

For a Graphic-Rich Exploration of these concepts, go Here.

**For Mutual Benefit,
Lives find ways to Live
With and Within Each Other**

**All Lives Exist in
Communities of Mutual Dependence**

Communities "Nest" Inside Each Other at Every Scale like Russian Dolls

Interliving is a Basic Organizing Pattern of Life

"…the driving force in nature…is cooperation."

—Lewis Thomas, in *The Fragile Species*

What is Interliving?

Interliving means living with and within other organisms. Biologists have for many years classified different forms of Interliving.

When both members profit from their association, it is **mutualism**.
When the mutualism is intimate, it is **symbiosis**.
When one member of an association benefits and the other is unaffected (as in epiphytic plants and tree bark lichens), it is **commensalism**.
When one benefits and the other is injured, it is **parasitism**.

The problem with this classification scheme is that **it ignores community**.

It speaks only of pairs of species.

However, we learn more every day about how every organism lives embedded in a dense mesh of mutual relationships.

We need new language which is not based in individualism or single species thinking.

We need categories which recognize that the community is what evolves.

The term **interliving** is more and more used for mutualisms at both the local and ecosystem levels.

For the purposes of this essay, the terms **ecosystem** and **community** may be used interchangeably.

Technically, ecosystem includes the non living parts of a natural community as well as the living.

All natural living systems, from the organism to the ecosystem, are open systems.

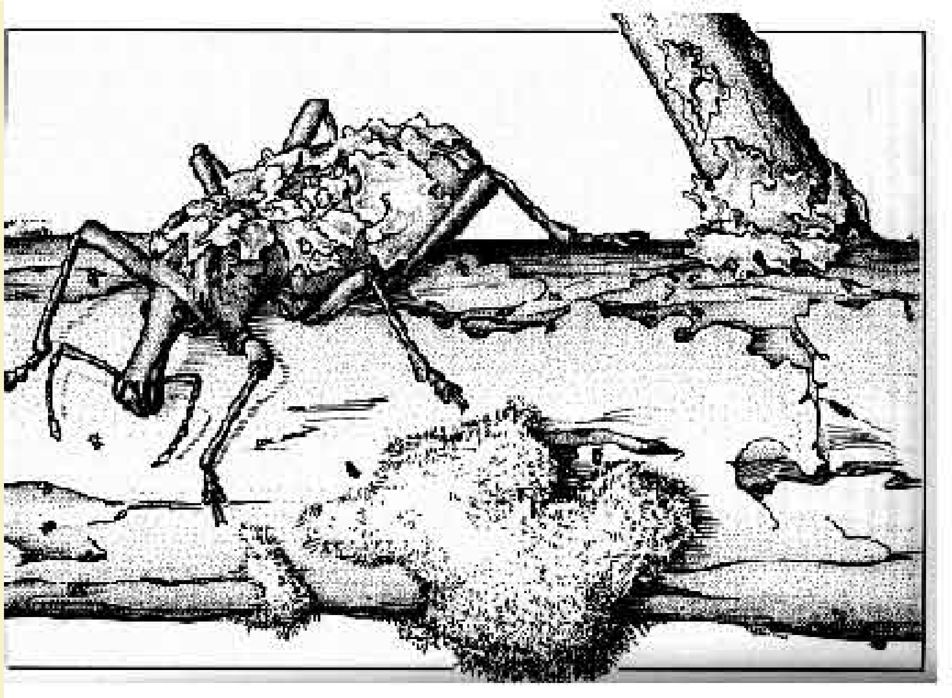
They take in matter and energy, use up the energy, and excrete unused matter.

Community size is always relative, like those nesting Russian dolls that each fit inside the next larger size. In other words, community size is a matter of the scale of observation we are using.

For example, imagine we are exploring a rainforest with an amazing camera, that can give us views all the way from telescopic size (pulling back, or zooming out) to microscopic size (zooming way in):

- If we pull far back to take in a large picture, we see a vast sweep of the tops of trees, rounded humps of leaves that together are the canopy layer of that whole forest.

- Now we zoom in to one section of the canopy layer. We zoom in closer to the top of a single tree. Now to one leafy branch, now to one stretch of bark along that branch. On the close-up branch we can make out a large weevil (a kind of beetle with a snout).



adapted from E.O.Wilson, *The Diversity of Life*
This large weevil carries a garden of lichen on its back, a microhabitat that supports several species of mites and springtails.

• The weevil is part of the community of that single tree, which supports the lives of many thousands of individuals of many species, most on the tree but some within the tree.

If we zoom even farther in on the weevil, we see some lichens growing on the weevil's back, and zooming farther in on the lichens we see tiny arthropods moving about. In those lichens live several kinds of springtails and mites, so we can describe the weevil's back as a community.

• If we continue to zoom in on the weevil to the microscopic level, we discover that inside the weevil's gut there are billions of bacteria living symbiotically with the weevil, without which the weevil could not digest its food. So the weevil itself is a community as well.

• Among the bacteria in the weevil's gut we see a comparatively enormous protozoan swimming vigorously. Zooming in on this one-celled eucaryotic creature we see bacteria inside it as well, so we can perceive this protozoan as a community.

Interliving is the most common living arrangement on Earth.

Everywhere on Earth for the past three billion years, living organisms have found mutually beneficial ways to live with each other, on each other, inside each other, and in response to each other.

Human intuition has always sensed this. But it is only in the past thirty years that science has demonstrated interliving to be the pervasive organizing pattern of life.

The conclusive evidence has come from micro-biology, especially from the genius of biologist Lynn Margulis.

> ***Symbiosis*** *has affected the course of evolution as profoundly as has biparental sex. Both entail the formation of new individuals that carry genes from more than a single parent…*
> *The genes of symbiotic partners are in close proximity; natural selection acts on them as a unit.*
>
> —Lynn Margulis

Some of our cherished cultural beliefs may impede our ability to grasp this new knowledge.

One such belief derives from the nineteenth century misreading of Darwin's Theory of Evolution called "social Darwinism":

Life is intensely competitive. It's a dog eat dog world. It's a jungle out there. In society, as in nature, the fittest survive. The fittest have the most money, that's how you know they're the most fit.

Circular reasoning? Yes.

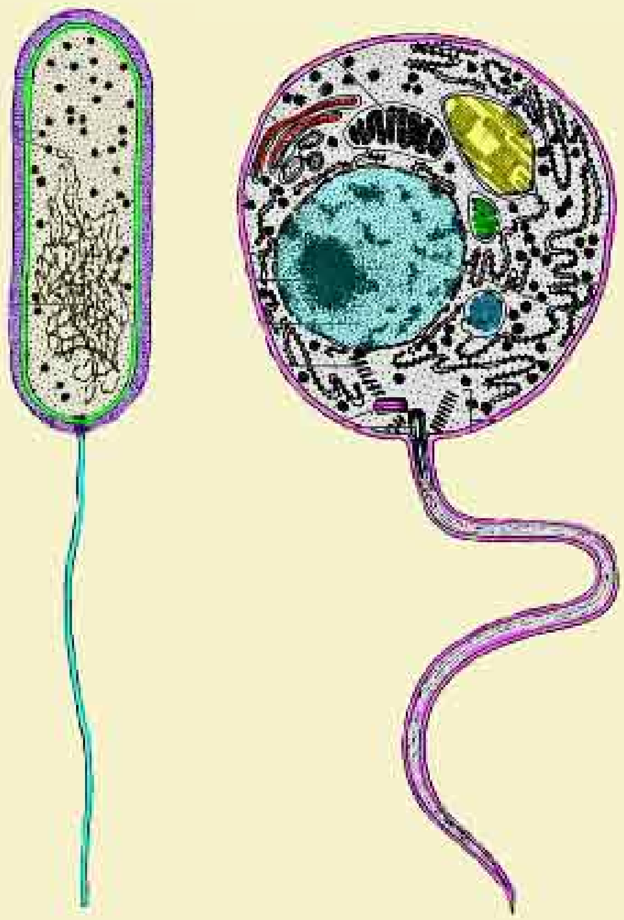
A jungle out there? Well, actually, no. Sure, competition exists. Sure, things eat each other. Yes, the lion's muzzle is red. No, it's not a jungle out there—**it's an ecology out there**.

The Origins of Interliving

Ecology is the study of relationships, the science that demonstrates how the strands of the web of life interweave.

Cellular biology shows us that even at the cellular level, life is essentially cooperative.

In the New Biology (the one that replaces what many were probably taught in high school), living organisms are divided into two enormous domains, Procaryotes and Eucaryotes.



Procaryote Cell, a bacterium, (left) with neither organelles nor nucleus
Eucaryote Cell, a protozoan, (right) with nucleus and mitochondria

Adapted from *Five Kingdoms*, Lynn Margulis and Karlene Schwartz

Without getting very technical, procaryotes are single cells that have fewer internal structures than eucaryotes. They do not have a nucleus. They do have DNA, but they use RNA different from eucaryotes. Until recently, we thought that all procaryotes were bacteria.

But in the past thirty years, a different kind of procaryote was discovered that had been "hiding in plain sight" all along, the **Archea,** so called because they are thought to be more ancient than bacteria. Archaea look similar to bacteria, but have enough genetic difference to be regarded as one of the three Domains of life: Bacteria, Archaea, and the Eucarya, which are younger than Procarya.

Eucaryotes are complex cells. They do have a nucleus. They do contain membrane-bounded specialized structures as well.

The eucaryotes are everything alive on earth that are not bacteria or archaea.

Eucaryotes include the single cell protists (algaes and protozoans) plus the three kinds of many-celled beings: plants, animals, and fungi, the forms of life that have become enormous compared to bacteria.

The origin of the eucaryotic cell have long been a puzzle: how did these fancier cells come to be?

The answer is now clear: **Through cooperation.**

A few decades ago, as biologists began to understand genetic inheritance by studying cell DNA, they discovered that within each of our billions of body cells are tiny power plants called **mitochondria**, which we require to stay alive.

The strange thing they found was that mitochondria are not related to us. The discovery that their DNA was not quite human DNA was the first big clue to solving the puzzle of how eucaryotic cells came to exist.

The answer has a long name: **symbiogenesis**. It means “beginning by symbiosis.” Symbiosis means “living together.” To oversimplify a very long and complex story, try this mind-experiment:

It is three billion years ago. You can see no plants, no animals. You are wading in warm and shallow ocean water. You are wearing wonderful microscope glasses, which allow you to easily observe incredibly tiny things.

Imagine that you scoop up some water in your hand, and see a floating single celled organism. Then, you see it invaded by a smaller single-celled organism, that wants to eat the large one. The attacker eats its way inside the larger organism.

Now imagine that the large cell and its invader just settle down, one inside the other; apparently, nothing is happening, at least nothing violent or dramatic.

Now time speeds up. Day and night follow each other so fast that night becomes a flicker. Eons quickly pass.

As you continue to observe the pool of water in your hand, you see that the invader remains inside the larger cell, and that both stay alive and actually appear to thrive.

As a matter of fact, when the large cell reproduces by **dividing** (fission) the invader divides at the same time, so the two new large cells each have their smaller invader cells inside them.

Now dip the water back into the sea, and come home to try to understand what you observed.

Somehow the large cell and the invader cell worked out a way of living together.

The invader was **mitochondria**, which is a small specialist in converting energy. It provided usable energy to the larger cell it had invaded.

The large cell in turn provided food and safety to the invader. They developed a kind of intimate interdependency and cooperation we call symbiosis.

Today every cell in every animal of Earth (including you) is this symbiotic type of cell.

The mitochondria in these cells provide efficient energy production through chemical processes, so we animals can metabolize our food.

Something similar must have happened with plants. But in today’s plant cells we have not just two, but three kinds of cells inter-living.

Based on DNA studies, microbiologists postulate a sequence of symbioses, one for the mitochondria, and two for distinct types of chloroplasts.

The third partner in every green plant cell is the chloroplast, which converts light energy into chemical energy. All animal cells depend on this transforming ability of green plant cells for their lives.

Now these once independent but now interdependent organisms cannot live without each other.

These marvelous and strange arrangements that previously independent bacterial organisms made so long ago demonstrate that cooperation is a fundamental condition of life on Earth.

Another Interliving Origin

We now know some more things about bacteria and archaea that challenge additional cherished beliefs:

• bacteria and archaea rarely naturally occur as aggregations of a single kind. Instead, bacteria live in communities of several species. A few are free-floating in the ocean, but most all live in biofilms. These "films" are layered communities held together by a gel the bacteria secrete; the layers of cells are penetrated by channels and shafts which carry oxygen, water, dissolved nutrients, and chemical signals. In large biofilms we find protists that find it a safe way to live. Microbes living in biofilms resist our antibiotics well, because of the gel that holds them together, and because some are alive but dormant toward the bottom layers.

• bacteria of all kinds freely exchange genetic material with one another. This called lateral gene transmission. This gives their communities enormous adaptive flexibility.

• A bacterial community is in effect a single interliving gene pool, swapping and using each other’s DNA continually (which is how bacteria can develop resistance to anti-biotics so rapidly). The species concept is not very useful with bacteria; at best, they have a sort of clan affiliation

• Bacteria and archaea are now and have always been the dominant life-form on earth. We are among their most interesting colonies.

Since the discovery of the germ theory of disease (Pasteur, 1866) humanity has been taught that bacteria are always the bad guys in our interactions; bacteria make us sick.

Wrong, mostly.

The fact that some bacteria do cause some human diseases has obscured the truth.

Most bacteria which have anything to do with us are beneficial.

More than that, without interliving bacteria inside them, no land animal could digest its food well enough to thrive.

So it turns out that bacteria are necessary to animal life. Every animal is itself a living system which has billions of other living systems interliving within it. Ten percent of my drybody weight is bacteria and archaea. So is yours.

When Walt Whitman said, *"I contain multitudes,"* he was incredibly correct.

Interliving Fungi

Another bizarre attitude we have is toward the fungi.

Fungi, like bacteria, are supposed to be bad guys—ringworm, athlete's foot, bread mold, candida, and so on.

It turns out however, that 95% of green plants (basically all of the flowering plants except aquatics) interlive with fungi and **cannot thrive without them**.

The fungus threads (mycelia) and the plant's fine root hairs intertwine and become inseparable. This interliving arrangement is called **mycorrhiza** (fungus roots)**.**

Green plants, as you know, are the nutritional foundation of animal life on land.

Now we have discovered that fungi and those green plants have worked out a living arrangement that enables the plant to absorb minerals more efficiently from soil and water. The plant in turn provides carbohydrates to the fungi.

We have traditionally thought of the trees in a forest as separate individual organisms.

In fact, it turns out that they all are growing in a mat of mycorrhizal fungi that connects them all.

A prairie works the same way. So we have to re-think a bit. When we say green plants support all animal life on land, we should be saying, **green plants interliving with fungi support all animal life on land.**

Nitrogen Made Available Through Interliving

Plants and animals cannot live without nitrogen. Nitrogen seems plentiful. As a gas it is 78% of earth's atmosphere.

But living organisms cannot take nitrogen directly from the air. So what do they do?

Enter the nitrogen-fixing bacteria and archaea. These tiny superheroes live in soil and transform gaseous nitrogen into a form that plants can use (ammonia).

These bacteria and archaea are major players in the nitrogen cycle, the cycling of nitrogen through the biosphere. Only a small percentage of atmospheric nitrogen is ever part of living organisms. But the part that is used by life is recycled over and over again.

Another interliving is found between a nitrogen-fixing species of cyanobacteria (a photosynthetic bacteria) and an aquatic fern.

Farmers in Vietnam cultivate these two organisms and sell starter colonies to rice growers. Rice fields sown with this fern and bacteria combination produce a crop-yield increase of 50 to 100%.

Another vast interliving arrangement becomes visible when we discover another specialist kind of bacteria (denitrifying bacterias) that use urea (vented by all animals) as an energy source.

They convert the nitrogen in the urea into a form plants can use, thus recycling the nitrogen.

Decay of dead animal and plant matter of all kinds is done by bacteria. The result of this process is recycling of the substances needed for life.

These life-materials remain in the Biosphere, where they have been cycling for many millions of years.

Dominant Land Animals Are Interliving with Protozoans!

Sound like a good tabloid story? But this one is true. The dominant land animals on earth are the insects, hands down.

In tropical regions, the keystone species in ecosystems are termites and army ants or safari ants. Take them away, and the whole community collapses.

Termites eat wood, among other things. Wood is made largely of cellulose, a chemical compound which is hard to digest. How is this problem solved? By interliving, of course.

In the guts of termites live one-celled flagellate protozoans which can digest the cellulose. Actually, they can't. The bacteria living inside the protozoans digest the cellulose. Here is a chain of symbiotic partners: bacteria with protozoans; protozoans with termites

The termites get their food digested and the protozoans get a warm and secure place to live, food provided.

Some species of termites don't have protozoans in their guts; instead, they raise fungus gardens, where they deposit chewed cellulose; which is digested by the fungus. The termites eat the fruits of the fungus that they raise.

These interlivings are elegant win-win arrangements; all partners are necessary.

Gas-Exchange: the Largest Interliving

The largest mutually beneficial interliving is between all plants and all animals. Every living thing must breathe, or respire.

Respiration is a system for gas exchange; we get rid of gases we can't use, and take in gases we can use.

Plants take in carbon dioxide, which they must have for photosynthesis, and get rid of the free oxygen they have created, which is of no use to them.

Animals, in this wonderful interliving balance, breathe in oxygen, which they must have for metabolism, and get rid of carbon dioxide. Everybody gets to breathe.

Coevolution: Interliving Through Time

All examples of interliving given so far are examples of **coevolution**. It becomes apparent, as we look at example after example of Interliving, that these arrangements for survival have evolved.

In other words, they have resulted from organisms finding mutual advantage in living together and in response to each other over long periods of time.

They have become so good at cooperating that in most cases they cannot live alone.

It is apparent that species do not evolve alone; they evolve in response to one another.

The community, not the species alone or the pair of species, is what evolves.

We are barely beginning to glimpse how densely interwoven are the mutual ties within living communities. **Reciprocity is the rule of life**, not the occasional exception.

Coevolution on the African Savannah

Like all communities, the African savannah communities provide many examples of interliving.

The famous acacia tree gives us two wonderful examples.

1) The African acacias have large thorns to deter grazing. Grazers on the lower branches get a double surprise. If they bite a leaf, ants pour out of the hollowed-out thorns and attack them. Thorns are a safe place to live. The acacia, in turn, gives the ants sugar-rich sap through nipple-like structures called nectaries.The interliving ants get to eat, live safely, and at the same time keep grazers away.

2)The **giraffe/acacia** interliving relationship may seem exotic.

Giraffes are grazers on higher tree leaves. That's their niche.

If on an open savannah acacias are the most common tree, the giraffe **must** eat acacia leaves.

Together giraffes and acacxias have evolved a system for coexistence.

If a giraffe begins to browse acacia leaves, the tree immediately begins pumping alkaloids into all its leaves which make its leaves not only nasty-tasting but poisonous to the giraffe.

So the giraffe only gets to eat a few acacia leaves from that tree.

Here is where the story gets interesting.

When the acacia begins its chemical defense, it releases a signal into the air, and all of the acacia trees **downwind** of the "injured" tree immediately begin to pump their own leaves full of poison too. You get a picture of a lot of hungry giraffes.

Giraffes, however, have found a way to browse acacias. They begin **upwind** and graze against the wind. They can still only get a few leaves from each tree before the leaves become too bitter, but as long as they work with the wind, they do get a meal.

This relationship is clearly not symbiosis in the traditional sense, but just as clearly it is coevolved interliving.

Although it is based in self-interest (as most everything is), the cooperation here is real. Both members of this collaboration get what they need.

I said above that this giraffe/acacia interliving may seem exotic. It is not; their pattern turns out to be a common pattern. It's quite ordinary, we are beginning to discover, for plants to be responsive to animals (especially insects) in many ways.

What tangled webs we do weave.

Interliving arrangements may always involve energy transfer (feeding)

Coevolution in the Ocean Shallows
(*adapted from Lyall Watson*)

Right now, in a galaxy of stars called the Milky Way, on the third planet of a smallish sun called Sol, there is a little silvery fish called a leiognathid that lives in warm muddy shallows in mangrove swamps of the Philippines.

(We'll just call them a little fish instead of repeating leiognathid).

In daylight you don't notice these little fish. They appear ordinary, just a five inch little fish. At night, though, these little fish are glorious; they shine and flash with a blue-green light.

Not only can this fish shine, but it can direct its light in three different ways.

It is equipped with three "shutters" made of opaque muscle—these sheets of muscle can close off the light when the fish wants.

The light "bulb" is an organ in the throat.

Each of these fish is equipped with its own "flashlight" —by using its muscle "shutters", it can project a bright beam of light forward through the water, which probably helps it catch its dinner.

When it closes the front shutter and opens a belly shutter, its whole underside glows.

The glow is brighter because it reflects off the fish's swim bladder, which has a silvery coating like a mirror.

When a predator approaches this fish, the little fish gives a sudden FLASH!! which startles the predator and helps its prey escape.

The odd thing is, though, that this leiognathid fish cannot make light.

In the ocean are free-living luminescent (light-making) bacteria.

When this fish is young, it swallows a lot of these little glowing specks in the night water, and instead of being digested, the bacteria go to a special organ in the fish's throat, where from then on they live and thrive and glow like mad.

These little fish borrow their light.

The fish receives light from the bacteria. The bacteria receive easy living and lots of food from the fish. Each partner benefits.

So what? What can this fish and these bacteria teach us about life?

- This is a story in which two kinds of life cooperate and both benefit.
- This is a story in which the whole identity and survival of a little fish depends on borrowing light from another life form.

We don't know how the young fish knows that it must now begin to swallow luminous bacteria, but it does know it.

One difference between humans and that little fish is that we learn and know things in very different ways.

What the fish know is "built-in," or encoded in its genes.
What you know is partly like that, but is mostly the result of learning.

The little fish borrowed light.

Predator/Prey Coevolution

We don't usually think of predator/prey relationships as cooperative, but viewed from the interliving perspective they clearly are.

Again, it is the community which evolves, each species responding to the other members.

We know now (hunters have always known) that predators keep the prey species healthy, and over the long run, improve the prey's speed and other means of escape. Whether it's wolves and moose, or cougar and deer in Canada, or lion and zebra in Africa, the interliving coevolution has resulted in more intelligence and ability on both sides of the relationship.

Like the giraffe and the acacia, together the members of communities co-evolve ways to coexist. Although such interliving patterns inevitably prove deadly to some individuals (including old predators), it ensures the survival of both species.

In Interliving, the community demonstrates intelligence.

There are many others examples of communities coevolving. They are each examples of a kind of cooperation extending through long stretches of time in which all participant species end up benefiting from the association. Here are a few more brief examples of coevolution.

Fruits Coevolved with Animal Seed-Dispersers

Plants evolved fleshy fruits (berries, fruits, nuts, acorns) as seed-packaging devices to disperse their seed. Fruits all evolved in cooperation with certain animals which eat the fruit (and seed), then excrete the unharmed seed away from the parent plant. Oak trees evolved acorns in a long cooperation with squirrels and bluejays. These animals buried (or planted) the acorns as stored food. The great oak savannas of North America were planted by squirrels and bluejays as part of this long coevolution.

Flowers Coevolved with Animal Pollinators

Many flowers have coevolved with one or more species of flying insect to insure pollination of the flower by another member of its species. Often, the structure of the flower is tailored to the size and shape of its pollinator.

The yucca flower opens only at night, when the yucca moth is flying. The moth has specialized mouthparts to collect and carry yucca pollen.
While visiting a flower, the moth takes a little ball of the pollen she is carrying and places it directly on the stigma of the flower, actively pollinating the flower and ensuring successful seed formation.

The moth then lays its eggs inside each flower it visits. But it only lays a few in each flower. When the moth’s eggs hatch, they feed on the developing seeds of the plant.

The plant is guaranteed pollination so it can make seed; the moth is guaranteed food and protection for her developing larvae.

Yes, the yucca loses some seeds (never all), but it gains far more in this coevolved relationship than it loses.

Flowering plants and hummingbirds coevolved long tubular flowers and long beaks mutually. Butterfly tongues and nectar at the bases of flowers coevolved.

Interliving : Wasps and Corn

Plants are obviously central to natural communities, but we don't know much yet about how plants behave in their communities.

Because they have roots and are not mobile, we tend to think they are not responsive.

But we are just beginning to change our minds about plants' abilities; we know that many plants can respond chemically to being attacked by emitting chemical signals called pheromones. Here is a recent newspaper account of plants responding to being eaten in a way that provided reproductive possibilities for an insect member of the community:

> WASHINGTON, DC. (Associated Press)—
> When caterpillars munch on corn leaves, the plant sends out a chemical alarm. Like airborne cavalry, tiny wasps fly to the rescue and turn the bad guys into lunch.
>
> By learning how wasps and corn cooperate, researchers hope to help farmers grow more food with fewer pesticides.
>
> "This is essentially an alliance between the wasp and the plants against herbivorous insects," said J.H.. Tumlinson of the Agricultural- Research Service in Gainesville, FL.
>
> In a study published today in the journal Science, Tumlinson and five other researchers say they have identified the role of a caterpillar secretion called *volicitin*.
>
> The beet army worm caterpillar—a pest of corn and cotton—drools *volicitin* as it chews on a leaf. *Volicitin* acts as a danger signal to the corn plant, Tumlinson said. "When the caterpillar chews on a leaf, the plant releases a chemical that is like an odor," he said. "The wasp uses this odor to find the caterpillar."
>
> The wasp dives onto the caterpillar, stings it and deposits eggs under the skin. The eggs hatch within a short time, and the larvae eat out the inside of the caterpillar to emerge as adult wasps.
>
> The corn-wasp alliance probably evolved by chance, Tumlinson said. To defend against leaf eaters, plants develop new chemicals that range from poisons to unpalatable flavors. At some point, the wasp learned that one of those chemicals was like a dinner bell for its young.
>
> "We've found we can teach the wasp. They are pretty smart," Tumlinson said. "If they find a caterpillar on a plant, they know what it smells like. They learn that

signal and start using it."

The cotton plant also attracts protective wasps, but with a different chemical system that is still not perfectly understood, he said. Researchers have found a cousin to the cotton plant that puts out an even stronger wasp attractant and are now trying to breed that characteristic into domesticated cotton, Tumlinson said.

"If we could put that into cotton, then when it is hit by caterpillars it could really light up and attract more wasps," he said.

The parasitic wasps used in the study are about the size of gnats, but are relentless hunters, Tumlinson said.

"They patrol the fields and search for places to put their eggs," he said.. By studying the wasp/plant alliance, science will find ways to make crops that are "wasp-friendly."

"If we can figure out what is going on in these plants, then we could breed crops that turn on a much stronger signal when they are attacked," Tumlinson said." Then the wasp wouldn't have to search so hard for the caterpillars, and more natural wasps would be lured into the field."

This story clearly describes behavior toward other species that we did not know plants were capable of until recently. We are not used to thinking of plants as responsive. It takes discoveries like this to force us to take our blinders off.

Caution We should remember that the wasp–plant alliance described in the story is the result of a long coevolution between insects and plants, and does not mean that plants or insects think and plan in the way that we do.

Fruit Ripening Coevolved with Bird Migration

In temperate biomes, fruits and berries coevolved with migrating birds; the plants “learned” to time their ripening for late summer, just when flocks of migrant birds would be coming through to eat them and disperse their seed. In tropical biomes fruits ripen all year round. This keeps pollinators and seed dispersers ready when the plant requires their service.s

When we add to the fundamental symbiotic relationships within eucaryotic cells the many other coevolved relationships between animals and plants, we begin to see that the reproduction of a majority of plants depends on cooperative relationships with both pollinator animals and seed disperser animals.

Parasitism: Pathological Interliving

The most clever definition of **parasitism** is E. O.. Wilson's: **predation in units of less than one**.

Parasitism is the pathological side of Interliving; it is Interliving gone wrong. The benefit in parasitism is all one way.

We find parasites morally repugnant, but that's our problem, not a problem with a very popular way of life.

It may be that life's tendency to combine has encouraged the genesis of parasitic relationships.

In many parasitisms by worms and other 'lower order' animals, the prey is multiple, a succession of organisms to accommodate different life-stages of the parasite. These parasites have, in effect, parasitized the community.

Again, to understand, we must not think in terms of individual organisms or species.

Increasing Diversity, Increasing Cooperation

What does all this Interliving mean? I don't know, but it is suggestive. It's a likable thing.

As time has passed, the tree of life has become ever more complex and diverse. The tree began to branch about 600 million years ago and has never stopped. Many leaves have fallen (gone extinct) during the wild growth of this incredible tree; probably 95% of all leaves that ever greened on Life's tree have fallen away.

We know that there were five periods when the Tree lost many of its leaves. But the roots and trunk were never in danger. When leaves do fall, the Tree just keeps branching and twigging and making more leaves.

Right now there are probably some 100 million species of living organisms on Earth. And they are each unique, different from all the other species.

In the ever-radiating branches of the tree of life, we see **a pattern of ever-increasing**

diversity. In the life-strategy called Interliving, we see a **pattern of increasing cooperation**. It is easy to find a little hope there.

Lewis Thomas put it well:

> The most inventive and novel of all schemes in nature, and perhaps the most significant in determining the great landmark events in evolution, is symbiosis, which is simply cooperative behavior carried to its extreme. But something vaguely like symbiosis, less committed and more ephemeral, a sort of wish to join up, pervades the Biosphere.
>
> —Lewis Thomas, in *The Fragile Species*

For a Graphic-Rich Exploration of these concepts, go Here.

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