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Symbiosis

Most of the interactions between species involve food:

* competing for the same food supply
* eating (predation)
* avoiding being eaten (avoiding predation)

These interactions are often brief. There are many cases, however, where two species live in close association for long periods. Such associations are called symbiotic ("living together").

In symbiosis, at least one member of the pair benefits from the relationship. The other member may be

* injured = parasitism
* relatively unaffected ( = commensalism)
* may also benefit ( = mutualism). (Some people restrict the term symbiosis to only these mutually beneficial interactions, but we shall not.)

Mutualism

Symbiotic relationships in which each species benefits are mutualistic. There are hundreds of examples of mutualism between a heterotroph and an [alga](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Plants.html#chlorophyta).

* Paramecium bursaria is a [ciliate](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Protists.html#Ciliates) that engulfs unicellular green algae into vacuoles within its cell.
  + The paramecium certainly benefits from the food synthesized by the alga. It can be cultured apart from the alga but then must be given extra food.
  + The alga presumably benefits from the carbon dioxide produced by its host as well as the host's ability to transport it to a spot where there is ample light.
* Many other aquatic heterotrophs
  + [sponges](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Porifera)
  + [sea anemones](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Cnidaria)
  + [planarians](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Platyhelminthes)
  + [clams](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Mollusks)

also harbor algae within their cells.

Mutualistic relations between plants and fungi are very common. The fungus invades and lives in or among the cortex cells of the secondary [roots](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/R/Roots.html). The association is called a mycorrhiza.

The fungus helps the host plant absorb inorganic nitrogen and phosphorus from the soil. Some mycorrhizal fungi also secrete antibiotics which may help protect their host from invasion by parasitic fungi and bacteria.

Many mushrooms are the spore-forming bodies of mycorrhizal fungi. The truffle [[View](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/F/Fungi.html#Ascomycetes)] is often found in oak forests because the fungus that produces it establishes mycorrhiza on oak roots.

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| [More on mycorrhizal fungi](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/F/Fungi.html#mycorrhiza) |

Endosymbiosis

Endosymbiosis is a mutualistic relationship between a host and an organism living within its body or cells.

The pea aphid and its endosymbiont

The pea aphid, Acyrthosiphon pisum, is an insect pest that sucks the juices from its host plant. However, plant sap is deficient in several essential amino acids. The pea aphid thrives nonetheless thanks to specialized cells within its body that contain [gamma proteobacteria](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#gamma_proteobacteria), Buchnera aphidicola, that can live nowhere else. The genome of these obligate intracellular [Gram-negative bacteria](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Classification_of_Eubacteria) encodes a number of enzymes needed to complete the synthesis of the amino acids needed by its host.

In return, the aphid's genome

* encodes enzymes needed by Buchnera to synthesize its [lipopolysaccharide cell wall](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Classification_of_Eubacteria) and
* has lost genes that might otherwise repel infection by Gram-negative bacteria.

Symbiotic nitrogen fixation

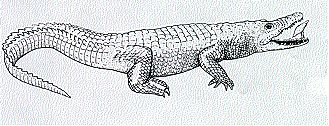
One of the most important examples of mutualism in the overall economy of the biosphere is the endosymbiotic relationship between certain nitrogen-fixing bacteria and their legume hosts.

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| [Link to a discussion.](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/N/NitrogenFixation.html) |

A large body of evidence supports the view that intracellular endosymbiotic relationships gave rise to eukaryotes with their mitochondria and chloroplasts.

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| Examine some of the evidence at [Endosymbiosis and The Origin of Eukaryotes](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Endosymbiosis.html) |

Cleaning Symbiosis

The drawing shows the Nile crocodile opening its mouth to permit the Egyptian plover to feed on any leeches attached to its gums.

Cleaning symbiosis is more common in fish.

Commensalism

Commensalism means "at table together". It is used for symbiotic relationships in which one organism consumes the unused food of another. Some examples:

* the remora and the shark. The dorsal fin of the remora (a [bony fish](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/V/Vertebrates.html#Bony)) is modified into a sucker with which it forms a temporary attachment to the shark. When the shark feeds, the remora picks up scraps. The shark makes no attempt to prey on the remora.
* Some species of [barnacles](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Crustacea) are found only as commensals on the jaws of whales. And there are other species of barnacles found only as commensals on those barnacles!
* Many of the bacteria living in our large intestine. They feed on food in the gut and do not harm us. And some probably help us; that is, the relationship is mutualistic [[Link](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Innate.html#commensals)]. Animals (e.g., mice) raised under germfree conditions are abnormal in several ways, and it is now standard practice to deliberately infect them with several species of microorganisms so that the animals develop normally. [[More](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Innate.html#commensals)]

Epiphytes

Epiphytes are plants that live perched on sturdier plants. They do not take any nourishment from their host and simply benefit from being better exposed to sunlight.

Some examples:

* many orchids
* many bromeliads (e.g., "Spanish moss" and other members of the pineapple family). [[View](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/B/Biomes.html#TropicalRainForest)]

Parasitism

A parasite is an organism that

* lives on or in the body of another organism (the host)
* from whose tissues it gets its nourishment, and
* to whom it does some damage

Animals are parasitized by viruses, bacteria, fungi, protozoans, flatworms (tapeworms and flukes), nematodes, insects (fleas, lice), and arachnids (mites).

Plants are parasitized by viruses, bacteria, fungi, nematodes, and a few other plants.

Parasites damage their host in two major ways:

* consuming its tissues, e.g., hookworms
* liberating toxins, for example,
  + Tetanus bacilli secrete tetanus toxin which interferes with synaptic transmission.
  + Diphtheria bacilli secrete a toxin that inhibits protein synthesis by ribosomes.

The relationship between parasite and host varies along a spectrum that extends from

* "hit and run" parasites that live in their host for a brief period and then move on to another with or without killing the first   
  to
* parasites that establish chronic infections. Both parasite and host must evolve to ensure the survival of both because if the parasite kills its host before it can move on, it destroys its own meal ticket.
* [Link to further discussion.](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/Games.html#AcuteVsChronic)

Rabbits in Australia

The mutual evolutionary adaptations of parasite and host may lead to the parasite becoming less damaging at the same time as the host becomes more resistant. Here is am example. 

In 1859, the European rabbit was introduced into Australia for sport. With no important predator there, it multiplied explosively. The raising of sheep (another imported species) suffered badly as the rabbits competed with them for forage.

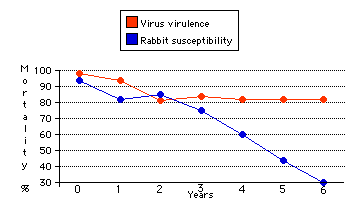
This picture (courtesy of Dunston from *Black Star*) gives you the idea. Having removed all forage plants, which ordinarily supply them with water as well as food, the rabbits had to drink from a pool.

In 1950, the myxoma virus was brought from Brazil and released. The epidemic that followed killed off millions of rabbits (perhaps 99.5% of the population). Green grass returned and sheep raising once again became profitable.

But the rabbits were not eliminated. In fact, although small epidemics still occur, the rabbit population has recovered somewhat (although nowhere near its pre-1950 levels).

What happened?

Thanks to careful planning, we know.

* The rabbits today are more resistant to infection than their predecessors. This can be measured by infecting them with the original strain that has been maintained in the laboratory.
* At the same time, the virus circulating in the wild rabbits has become less virulent. This can be measured by determining the % mortality of laboratory rabbits when they are infected with the current strain of virus.

The graph (based on data of Sir Macfarlane Burnet and D. O. White) shows these mutual evolutionary adaptations over the first six years after the introduction of the virus.

The "Degeneracy" of Parasites

During the course of adapting to conditions in their host, parasites often lose structures and functions that were essential for their ancestors (and any free-living relatives).

The tapeworm has no eyes, no digestive tract, and only vestiges of nervous, excretory, and muscular systems.

While you may call them degenerate, these losses represent a gain in efficiency and improved specialization. What good would these structures be anyway in the human intestine? On the other hand, the tapeworm produces hundreds of proglottids [[View](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/T/Tapeworms.html#Taenia_solium,_the_pig_tapeworm)]: egg-forming machines that improve the likelihood that the tapeworm will leave descendants that reach another host.

This emphasis on reproduction is also seen in

* Rafflesia, a parasitic [angiosperm](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/Angiosperm.html) found in Malaysia. It has no roots, stems, or leaves, although it does have tubes which penetrate the tissues of its host. But it has a huge flower (~3 feet or 1 meter in diameter).
* Sacculina, a barnacle that parasites crabs. The adult consists of little more than a sac (hence the name) containing reproductive organs. Not until its larvae were discovered could it even be determined that Sacculina was a [crustacean](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Crustacea).

Mycobacterium leprae

M. leprae causes leprosy (Hansen's disease). It is an intracellular parasite, taking up residence in [Schwann cells](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/ExcitableCells.html#myelin) where, in due course, it triggers an autoimmune attack on them that leads to their destruction. The resulting loss of sensation makes it difficult to avoid injury to the extremities.

M. leprae is a [mycobacterium](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Mycobacteria_and_Corynebacteria) and a close relative of M. tuberculosis, the cause of TB.

Although it was the first bacterium to be identified as a cause of human disease (in 1873), no bacteriologist has ever succeeded in cultivating it in vitro. It can, however, be propagated (slowly) in the nine-banded armadillo, and this has provided enough material to sequence its entire genome.

Its sequence, which was published in the 22 February 2001 issue of Nature (Cole, S. T. et al.) — when compared to that of M. tuberculosis — provides a vivid demonstration of degeneracy at the level of the genes.

Although its genome is only about 25% smaller than that of M. tuberculosis, it has only 40% of the genes of its cousin. Many of the missing genes are still detectible, but they are now pseudogenes — genes that have mutated so that they can no longer be expressed in a protein product.

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|  | M. tuberculosis | M. leprae |
| Size of genome (bp) | 4,411,532 | 3,268,203 |
| Protein-coding genes | 3.959 | 1,604 |
| citrate synthase genes (for [citric acid cycle](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/C/CellularRespiration.html#The_Citric_Acid_Cycle)) | 3 | 1 |
| pyruvate dehydrogenase genes (for citric acid cycle) | 6 | 2 |
| lactate dehydrogenase genes (cellular respiration) | 2 | 1 |
| phosphofructokinase genes ([glycolysis](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/Glycolysis.html)) | 2 | 1 |

M. leprae is not an exception. The many [bacterial genomes](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/GenomeSizes.html) that have now been sequenced show that bacteria that are obligate intracellular parasites express far fewer proteins than bacteria that can live on [culture medium](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/M/Media.html).

A collection of links to examples of parasites

* Viruses
  + [Retroviruses](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/R/Retroviruses.html), incl HIV-1, the cause of [AIDS](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/AIDS.html)
  + [Influenza](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Influenza.html)
  + [an assortment of others](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/V/Viruses.html)
* Bacteria, the agents of
  + [tetanus, botulism, and anthrax](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Gram_Positive_Rods)
  + [typhoid, cholera, and plague](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Gram_Negative_Rods)
  + [staphylococcal and streptococcal infections](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Gram_Positive_Cocci)
  + [gonorrhea](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Gram_Negative_Cocci)
  + [tuberculosis, leprosy, and diphtheria](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Mycobacteria_and_Corynebacteria)
  + [syphilis and Lyme disease](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Spirochetes)
  + [typhus fever and Rocky Mountain spotted fever](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Rickettsias)
* Protists
  + [Plasmodium](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/P/Protists.html#Sporozoans) (agents of malaria)
  + [Trypanosomes](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/Games.html#Trypanosoma_brucei)
* Invertebrates
  + [Tapeworms](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/T/Tapeworms.html)
  + [Blood flukes](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Platyhelminthes)
* [Games Parasites Play](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/G/Games.html) (some interesting interactions between host and parasite).

The Evolution of Symbiosis

It seems plausible that what begins as a parasitic relationship might over the course of time evolve into a mutualistic one as the two organisms evolve to minimize the damage to the host.

And there is some evidence for this. In 1966, K. W. Jeon discovered a culture of amoebas that had become infected with bacteria (60,00 to 150,000 per cell). The infection slowed their rate of growth and made them much more fragile. But five years later, the amoebas still were infected but now no ill effects could be seen. Most interesting for our question, the amoebas — or at least their nuclei — had become dependent on the bacteria.

* When the nucleus was removed from an infected amoeba and replaced with one from a uninfected strain, the combination worked fine.
* But when the nucleus from an uninfected cell was replaced with one from an infected cell, the combination usually failed to survive.

Evidently, after 5 years, the nuclei had become dependent on a bacterial function (an enzyme produced by the bacteria but no longer by the host). What started as parasitism had evolved into mutualism (the bacteria could not be grown outside their host).

But it doesn't always work like that. There are other examples where a mutualistic relationship seems to have evolved into a commensalistic or even parasitic one. Some parasitic fungi seem to have evolved from ancestors living in the mutualistic partnership of a [lichen](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/F/Fungi.html#lichens).

Some of the bacteria living in our large intestine supply us with [vitamin K](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/N/Nutrition.html#vitaminK), thus evolving from commensalism to mutualism.

Mutually beneficial symbiotic relationships can lead to "[degeneracy](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/S/Symbiosis.html#degeneracy)" also. Some marine [annelid worms](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/I/Invertebrates.html#Annelida) have completely lost the digestive tract of their relatives (like the common earthworm). One species gets its nourishment from a large population of at least 5 different species of bacteria living underneath its outer skin. The most abundant of these are [chemoautotrophs](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Chemoautotrophic) (but these bacteria are [gamma](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#gamma_proteobacteria)- and [delta](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#delta_proteobacteria)- proteobacteria not beta-proteobacteria) that manufacture food from carbon dioxide using the energy provided by oxidizing inorganic substances ([H2S](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/E/Eubacteria.html#Chemoautotrophic), H2) in the sediments in which the worm lives.

The nature of a symbiotic relationship can also change as circumstances change. Some fungi, bacteria and protozoans that live harmlessly in most of us can cause opportunistic infections — that is become parasitic — in immunodeficient people, e.g., those with AIDS [[Discussion](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/A/AIDS.html#Progression)].

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| [Welcome&Next Search](http://users.rcn.com/jkimball.ma.ultranet/BiologyPages/W/Welcome.html) |

15 December 2010