Bacteria — many good guys and bad guys.

The world of microbial diversity is way huger than anything we ever imagined. And, we owe our very existence to it! So, let’s not just think about the Bacteria that most people think about, those that cause us insignificant humans disease, but all of the Bacteria of the world, good and bad.
Back to the beginning . . .

* Remember, the first organisms of the world were microbes. They descended from LUCA. They've been around for more than 3.5 billion years, 'shortly' after the earth's crust formed!

* Whether they were Bacteria, or Archaea, or something else entirely, is completely unknown. It doesn't matter.

* Many of them went on to evolve into all the different Archaea. Others . . .
Diverged even further, to became the wild diversity of Bacteria we are about to explore.

And some of these got ‘eaten up’ by others, the partnerships worked out well, and endosymbiosis got started; several times — with aerobic Bacteria once, and many times with Bacteria that...

Sometime around 3+ billion years ago, had evolved photosynthesis.

These events collectively, eventually, produced the huge diversity of Eukaryotes that we will see later.

Meanwhile, other photosynthetic Bacteria went on to change the world by making oxygen, and as they say, the rest is history. But still others went on to...
To use every conceivable energy source;
And every conceivable carbon source.

... Evolve to fill every nook and cranny of the world ...
Here's some cool examples of the various metabolic activities they can exhibit.

<table>
<thead>
<tr>
<th>Energy Source:</th>
<th>Carbon Source:</th>
<th>Name:</th>
<th>Example:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>Inorganic</td>
<td>Photoautotroph</td>
<td>Most Photosynthetics: <em>Chromatium</em> (anaerobic); <em>Cyanobacteria</em> (aerobic)</td>
</tr>
<tr>
<td>Light</td>
<td>Organic</td>
<td>Photoheterotroph</td>
<td>Purple and Green Photosynthetics; <em>Rhodospirillum</em></td>
</tr>
<tr>
<td>Inorganic</td>
<td>Inorganic</td>
<td>Chemolithotrophic autotroph (Chemoautotroph)</td>
<td><em>Nitrobacter</em></td>
</tr>
<tr>
<td>Inorganic</td>
<td>Organic</td>
<td>Chemolithotrophic heterotroph (mixotroph)</td>
<td><em>Desulphovibrio</em></td>
</tr>
<tr>
<td>Organic</td>
<td>Inorganic</td>
<td>Chemoorganotrophic autotroph</td>
<td><em>Pseudomonas oxalatus</em></td>
</tr>
<tr>
<td>Organic</td>
<td>Organic</td>
<td>Chemo (heterotroph)</td>
<td><em>Escherichia coli</em></td>
</tr>
</tbody>
</table>

*There is no known naturally-occurring carbon-containing molecule which cannot be metabolized by at least one species [of Bacteria].*

And they move in all sorts of different ways. Here’s a cool one:

To reiterate . . .

* The domain Bacteria has . . .
* At least 23 different phyla (kingdoms?).
* And they, like Archaea, are extremely diverse, with photosynthetic ones, only some of which produce oxygen; with ones important in nitrogen and/or sulfur cycling; with commercially important ones in food production; with medically important ones — good and bad; and with ones that were the original source of many antibiotics.
I showed a slide like this before. Don’t stress over all the names. That’s not what I need you to remember — it’s the diversity that counts!

The 23 Bacterial ‘phyla’ —

- Actinobacteria
- Aquificae (maybe ancestral?)
- Bacteroidetes/Chlorobi group
- Chlamydiae/Verrucomicrobia group
- Chloroflexi (green nonsulfur bacteria)
- Chrysiogenetes
- Cyanobacteria (blue-green algae!)
- Deferrribacteres
- Deinococcus-Thermus (also ancient)
- Dictyoglomi
- Elusimicrobia
- Fibrobacteres/Acidobacteria group
- Firmicutes (One of the gram-positive bacteria groups)
- Fusobacteria
- Gemmatimonadetes
- Nitrospirae
- Planctomycetes
- Proteobacteria (aerobic purple bacteria and relatives!)
- Spirochaetes
- Synergistetes
- Tenericutes
- Thermodesulfobacteria
- Thermotogae (who’s ancestors are another really, really old one!)

And all of these names are hyperlinks, so you can explore them further at NCBI.
And here's a table, a rough way to categorize them. But often not phylogenetic...

<table>
<thead>
<tr>
<th>Group</th>
<th>Features</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proteobacteria</strong></td>
<td>Of whom's ancestors gave rise to all mitochondrion in endosymbiosis!</td>
<td></td>
</tr>
<tr>
<td>Purple sulfur bacteria</td>
<td>Bacterial photosynthesis using H$_2$S (not H$_2$O) as electron donor</td>
<td><em>Chromatium vinosum</em></td>
</tr>
<tr>
<td>Enteric bacteria</td>
<td>Rod-shaped, facultative anaerobes in animal intestinal tracts</td>
<td><em>Escherichia coli, Salmonella species (cause gastrointestinal disease)</em> Not all of them!</td>
</tr>
<tr>
<td>Vibrios</td>
<td>Comma-shaped, facultative anaerobes common in aquatic environments</td>
<td><em>Vibrio cholerae (causes cholera)</em></td>
</tr>
<tr>
<td>Spirochetes</td>
<td>Spiral-shaped; some pathogens of animals</td>
<td><em>Borrelia burgdorferi (causes Lyme disease)</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Treponema pallidum (causes syphilis)</em></td>
</tr>
</tbody>
</table>
| Cyanobacteria                 | Photosynthesis releases O$_2$, some fix nitrogen; free-living or symbiotic with plants, fungi (lichens), or protists | *Nostoc, Anabaena* ...
|                               |                                                                          | ancestors of chloroplasts.                      |
| **Gram-positive bacteria**    | Not a phylogenetic grouping — rather merely a physical characteristic!   |                                                |
| Endospore-forming bacteria    | Aerobic or anaerobic; rods or cocci                                      | *Bacillus anthracis (causes anthrax), Clostridium tetani (causes tetanus)* |
| Actinobacteria                | Filamentous                                                               | *Streptomyces*                                  |
Some nice Web sites allow you to navigate through the major groups.

- Such as the University of California’s Museum of Paleontology: http://www.ucmp.berkeley.edu/bacteria/bacteriasy.html, though not all is built.
- And the Tree of Life: http://www.tolweb.org/Eubacteria/ — they have movies and images too. Visit a few, particularly “ruminants”.
- http://www.bacteria-world.com/ has a lot of great photomicrographs.
- http://www.microbesonline.org/ quickly gets you to all sorts of neat Bacterial stuff.
And Howard Hughes Medical Institute’s "BioInteractive" even has a "Virtual Bacterial ID Lab."

"Welcome to the Virtual Bacterial Identification Lab. The purpose of the lab is to familiarize you with the science and techniques used to identify different types of bacteria based on their DNA sequence. Not long ago, DNA sequencing was a time-consuming, tedious process. With readily available commercial equipment and kits, it is now routine. The techniques used in this lab are applicable in a wide variety of settings, including scientific research and forensic labs."

http://www.hhmi.org/biointeractive/vlabs/bacterial_id/
Nature, the premier scientific journal of the world, along with Science, has a special Web focus on “Microbial Genomics.”

* http://www.nature.com/nature/focus/microbialgenomics/

* It provides access to the abstracts (or complete articles with a subscription) of many current manuscripts related to Bacterial diversity.
The Annenberg Foundation’s “Rediscovering Biology” series has a fantastic module on “Microbial Diversity.”

I realize you may be getting tired of all the videos I show, but . . . sometimes the ‘real’ experts can do a much better job of getting the point across to you than I can. And getting this information from as many different sources as you can, ‘repetition,’ can only help you learn.

So here’s another video that I think you’ll enjoy. Keep in mind that they’re mainly talking about Bacteria here, but include some Archaea as well: http://www.learner.org/courses/biology/units/microb/. It’s almost half an hour.
We’ll talk about Bacterial sex next and . . .

All the wild ways they can throw their genes around.

As well as a little diversion into genomics.
Bacterial promiscuity — sexier than you thought.

Even Bacteria have sex! But it’s not the usual way we think of. There’s no fun. No mixing of gametes. No fertilization. No zygote. But there is a mixing of genes. Bacterial sex involves the exchange of genes from one bacterium to another (as does most sex) but it’s a one way exchange — and it happens lots of different ways. Plus they’re really kinky — they even do it between species, between phyla, even between domains of life!
Their standard way of reproducing is kinda boring, but VERY efficient!

* That is asexual reproduction, via binary fission.

* Some bacterial cells can produce a new generation every 20 minutes.
Do I have stress?!

Just imagine, you would have to reproduce yourself every 20 minutes!

That would be stressful!
It kinda boggles the mind.

http://www.youtube.com/watch?v=gEwzDydiWc
But it's hard to get much variation this way.

Random mutation is the only source of genetic diversity this route. It works, but is quite slow, even in an organism like Bacteria that can reproduce so quickly.

However, horizontal gene transfer, i.e. bacterial sex, evolved billions of years ago, probably along with the very first cells. There are three main mechanisms:

1. Transformation – a take up of naked DNA without cell-to-cell contact. How boring . . .

2. Transduction – a phage transfer of DNA to a host cell. OK, but the virus gets to have all the fun.

3. Conjugation – a transfer of DNA using a sex pilus – now we're talking, but it's only a one way transfer.
Really! Bacterial sex. You gotta be kidding.

Yep, and as I said, there's lots of ways they do it. Here's those main three.
Transformation is one of the main tools of genetic engineering.

* That’s how we get foreign DNA into other critters, especially lab bacteria, in order to get them to make something, like recombinant insulin, that they don’t normally make. More on this later.

* And we’ve figured out how to do it with things other than just bacteria.

* Which is how we’ve engineered many commercially important crops.
Here's an animation of the process in the lab.

http://highered.mcgraw-hill.com/sites/0072556781/student_view0/chapter13/animation_quiz_1.html
The thing is, bacteria can do it in nature, all on their own.

* They can just ‘suck’ up little bits and pieces of all sorts of foreign DNA floating around. Often this comes from dead relatives!

* Although they have no ‘idea’ whether the random chunk of DNA they are sucking up will help them or not, they do it anyway.

* But sometimes it does help! And they can cruise off on some other new and exciting evolutionary trajectory. But most of the times it doesn’t. Although it seldom hurts.
Natural transformation, hmmm . . .

* http://www.learner.org/courses/biology/archive/animations/hires/a_infect3_h.html
* and also at http://www.youtube.com/watch?v=MRBdbKFisql
And what's this transduction thing?

- It takes a virus, a special virus that only attacks bacteria, called a bacteriophage. Particular phage attack particular bacteria – they are very discriminatory.

- The virus acts as a “vector,” transferring DNA from one bacterium to another.

- [Website Link](http://highered.mcgraw-hill.com/sites/0072556781/student_view0/chapter17/animation_quiz_3.html)
Ho hum, that’s all getting pretty boring.

* So what’s conjugation?
* It uses a sex pilus, and . . .
* Transfers DNA, especially the ‘sex fertility factor’ and antibiotic resistance genes between bacteria . . .
* Usually on a plasmid.
Here's an animation of conjugation.

Conjugation is a mechanism of gene transfer that requires direct contact between donor and recipient cells.

[http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter18/bacterial_conjugation.swf](http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter18/bacterial_conjugation.swf)
And another . . .

http://www.bio.fsu.edu/~stevet/VSV/animations/
Chapter18/conjugation-lg.wmv
And one more time...
The amazing thing is . . .

- This has happened many times even from Bacteria to Eukaryotes!
- Especially with the Bacteria that galls in plants, *Agrobacterium*. Their genes have been found in many of their host plants, and also in yeast and other fungi.
- But it’s also been demonstrated with other Bacteria and with Archaea, into some protists, and even into some animals.
Here’s an overview of all three mechanisms, and some cool human uses of them, from the Annenberg Group, the same people that did “Rediscovering Biology.”

http://www.learner.org/resources/series121.html
And . . . Bacterial Genomics?

- What makes this any different than any other type of genomics?
- Mainly – a lot more can be done a lot quicker and a lot easier, because Bacteria (and Archaea) have much smaller genomes than eukaryotes (on average, around 3+ million, versus 3+ billion!). So you can compare entire genomes, not just individual chromosomes.
- Plus, their genes are a lot easier to find, since they generally don’t have introns.
- One of the things we’ve seen with this approach is just how promiscuous they are!
So here’s our old friend *Escherichia coli*.

Its genome shows a slew of genes that were introduced by lateral gene transfer. These are represented as colored bars here. By analyzing GC-content, codon usage bias, dinucleotide frequencies, and other genomic "fingerprints," it can be seen that almost 18% of this genome came from foreign DNA introduced in at least 234 separate events, for a rate of about 16 kb/ MY of evolution.

And, as I said, it’s relatively easy to compare their genomes.

* Here two strains of the Mycobacterium that cause tuberculosis.

And here in ‘dotplot’ fashion...

Two species of Mycoplasma, one that causes pneumonia and one that can cause pelvic inflammatory disease. They have really tiny genomes, genitalium one of the smallest known!

There's even entire Web sites devoted to these types of analyses; e.g. see . . .

The Microbial Genome Database for Comparative Analysis
(http://mbgd.genome.ad.jp)
And the Comprehensive Microbial Resource at the J. Craig Venter Institute. Here Bacillus anthracis is compared to Bacillus cereus in a dotplot representation.

http://cmr.jcvi.org/tigr-scripts/CMR/CmrHomePage.cgi
And now . . .

* We'll survey those Bacteria that we always think about, those that can cause human disease, . . .

* And of those that we never really think of, those that do us all sorts of good.
Bacterial bad guys, disease, and antibiotic resistance

Let's look at a few of the bacteria that most everybody automatically thinks of when the word "bacteria" is mentioned — those that cause disease in humans. But, remember, these really are the exception. Most bacteria cause no trouble for humans, and, as we’ll explore after this, many are absolutely essential to our, and the planet’s, well being. But, yes, there are some really nasty ones out there . . . .
Let’s start out with the stereotype (and some humor).

http://www.youtube.com/watch?v=tqOVYpkZ0qs
OK, now let's get serious.

- Some human disease is caused by bacteria.
- There are many points of entry for the invaders, e.g. open wounds, insect bites, our eyes, sexual contact, inhalation, and ingestion.
- Some bacteria produce toxins and that's what causes the problem. Most pathogenic ones also cause infection — the body's immune system struggles to overcome the bacteria and the symptoms result from this immune response.
- There are also many ways for the bacteria to exit the body, e.g. sneezes and coughs, semen and vaginal fluids, feces, and blood.
The Howard Hughes Medical Institute has a marvelous teaching module entitled “When Worlds Collide . . .”

“Micro versus Macro.” Let’s take the time to go through some of it:


And they have one just on leprosy:

http://www.hhmi.org/biointeractive/disease/leprosy/index.html
The Centers for Disease Control and Prevention . . .

* Have a slew of resources, including a bacterial disease listing providing in-house information on most all bacterial diseases:


* Wikipedia has a similar resource:

Many common diseases are caused by bacterial toxins. Exotoxin proteins are secreted by bacteria. Bacteria also have nonsecreted endotoxins, which are released when the bacterium dies. Both contribute to the symptoms of the associated disease.

<table>
<thead>
<tr>
<th>Disease</th>
<th>Organism</th>
<th>Toxin</th>
<th>Effects in vivo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetanus</td>
<td>Clostridium tetani</td>
<td>Tetanus toxin</td>
<td>Blocks inhibitory neuron action leading to chronic muscle contraction</td>
</tr>
<tr>
<td>Diphtheria</td>
<td>Corynabacterium diphtheriae</td>
<td>Diphtheria toxin</td>
<td>Inhibits protein synthesis leading to epithelial cell damage and myocarditis</td>
</tr>
<tr>
<td>Gas gangrene</td>
<td>Clostridium perfringens</td>
<td>Clostridial toxin</td>
<td>Phospholipase activation leading to cell death</td>
</tr>
<tr>
<td>Cholera</td>
<td>Vibrio cholerae</td>
<td>Cholera toxin</td>
<td>Activates adenylate cyclase, elevates cAMP in cells, leading to changes in intestinal epithelial cells that cause loss of water and electrolytes</td>
</tr>
<tr>
<td>Anthrax</td>
<td>Bacillus anthracis</td>
<td>Anthrax toxic complex</td>
<td>Increases vascular permeability leading to edema, hemorrhage, and circulatory collapse</td>
</tr>
<tr>
<td>Botulism</td>
<td>Clostridium botulinum</td>
<td>Botulinum toxin</td>
<td>Blocks release of acetylcholine leading to paralysis</td>
</tr>
<tr>
<td>Whooping cough</td>
<td>Bordetella pertussis</td>
<td>Pertussis toxin</td>
<td>ADP-ribosylation of G proteins leading to lymphoproliferation</td>
</tr>
<tr>
<td>Scarlet fever</td>
<td>Streptococcus pyogenes</td>
<td>Erythrogenic toxin</td>
<td>Vasodilation leading to scarlet fever rash</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Leukocidin Streptolysins</td>
<td>Kill phagocytes, allowing bacterial survival</td>
</tr>
<tr>
<td>Food poisoning</td>
<td>Staphylococcus aureus</td>
<td>Staphylococcal enterotoxin</td>
<td>Acts on intestinal neurons to induce vomiting. Also a potent T-cell mitogen (SE superantigen)</td>
</tr>
<tr>
<td>Toxic-shock syndrome</td>
<td>Staphylococcus aureus</td>
<td>Toxic-shock syndrome toxin</td>
<td>Causes hypotension and skin loss. Also a potent T-cell mitogen (TSST-1 superantigen)</td>
</tr>
</tbody>
</table>
Urinary tract infections and sexually transmitted diseases are most often caused by bacteria.

- This one causes gonorrhea:

- And this video discusses how we can use cranberry juice to help fight UTIs:
Gum and tooth problems...

Periodontal disease caused by plaque is an effect of a bacterial biofilm.
Ulcers

* Heliobacter pylori causes these!
* http://www.bio.fsu.edu/~stevet/VSU/videos/Chapter18/Heliobacter.mov
Food poisoning

* Perhaps the best source of true information on the Internet regarding foodborne illnesses is from the FDA, their “Bad Bug Book:”

* http://www.fda.gov/Food/FoodSafety/FoodborneIllness/FoodborneIllnessFoodbornePathogensNaturalToxins/BadBugBook/default.htm

* It’s got all the info’ you’d ever want on every type of food poisoning imaginable.
An HHMI animation shows how a pathogenic strain of *E. coli* infects a gut cell.

http://www.hhmi.org/biointeractive/media/ecoli-lg.wmv
And another shows *Salmonella* doing the same thing.

http://www.hhmi.org/biointeractive/media/salmonella-lq.wmv
Here’s a video talking about bad versus good E. coli.

Particularly as it relates to hamburger!

http://www.bio.fsu.edu/~stevet/VSU/videos/Chapter18/ecoliwars_144.mov
Proper temperature control helps prevent food poisoning.

http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter18/food_pathogens_final.swf
Antibiotic resistance . . .

* Is evolution in action, at top speed!

Two PBS modules discuss the phenomenon.

http://www.pbs.org/wgbh/evolution/survival/clock/index.html

Staphylococcus aureus is the causative agent of a 'staph' infection.

A wide range of symptoms can be caused by different strains, including a really nasty one, MRSA (methicillin resistant S. aureus). This strain rapidly gained other antibiotic resistances and the percentage of hospital isolates that were MRSA rapidly increased, as seen here.
A phylogenetic analysis showed that both MRSA (in red) and strains associated with “toxic shock syndrome” (in blue) had multiple origins. Therefore the inference is that the mutation, after it had arose, had been passed around through horizontal gene transfer.
But we can also use bacterial evolution to our advantage.

* Cholera is an example:
However, most bacteria are... good ‘bugs’

* Let’s now see how we owe our very lives to bacteria, and how we’ve harnessed many of them to work for us!
Bacterial good guys — work for us and are absolutely necessary

Even though most people automatically only think of bacteria as causing disease, most of them are incredibly beneficial to us humans, and, in fact, to the entire ecosphere!
They’ve been here WAY longer than we have, and have been coevolving with all life for billions of year!

* We’ve discussed harmful bacteria. But there are literally tons and tons of bacteria that help us as well; some are essential to . . .
* Maintaining oxygen, nitrogen, and other essential elemental balances in the ecosphere; others are . . .
* Absolutely essential to our health;
* Some make our food, some make our vaccines, and many help . . .
* Decay dead things and return the nutrients to the soil (the original ‘think green’ recyclers)!
Bacteria in the environment...

* Do an enormous number of vital jobs, e.g....
* Oxygen production,
* Nitrogen fixation and cycling, and...
* Sulfate and iron reduction.
Let’s not forget oxygen!

The original Cyanobacterial ancestors charged the atmosphere with oxygen starting around 3.5 billion years ago, and by 2.5 billion years ago it had achieved pretty much current levels!

And they just keep doing it. Plus they fix atmospheric nitrogen. And, oh yeah, there’s that endosymbiosis thing!
Assimilation of nitrogen into organic compounds

Ammonia is incorporated into organic compounds by all organisms. Some bacteria are capable of converting atmospheric nitrogen to ammonia, and most bacteria, fungi, and plants can utilize nitrate from soil.

All life needs nitrogen: It’s in both protein and DNA/RNA!
Nitrogen fixation?

Many other species would die without this.

It converts atmospheric nitrogen gas (N₂) to ammonia (NH₃) “fixing” nitrogen for the ecosphere.

Rhizobium live in legume (e.g. peas, soybeans, beans, alfalfa) root nodules in a symbiotic relationship.
Nitrogen-fixing bacteria-legume symbiosis

Rhizobia are able to fix N\textsubscript{2} alone only under microaerophilic conditions (too much O\textsubscript{2} inhibits nitrogenases).

In the nodule, O\textsubscript{2} levels are kept low by the O\textsubscript{2} binding protein leghemoglobin.

90% of leguminous plants can undergo nodulation, but the legume-Rhizobia symbiosis is species-specific.
A number of nod genes are required for nodulation.

The nod genes control species-specific nodulation in Rhizobium.

The nif genes are required for nitrogen fixation.

They are often found on plasmids.
They also do lots of other things in the “nitrogen cycle.” Nitrogen oxidizers (nitrification) are common in soil and water, e.g. *Nitrosomonas* and *Nitrobacter*.
Denitrification is important for nitrogen cycling, as well as decreasing the amount of fixed (usable) nitrogen in sewage treatment effluent or other environments that can lead to unwanted algal blooms.
Sulfate reduction

For example:
Desulfovibrio desulfuricans

**Dissimilative sulfate reduction**

**Assimilative sulfate reduction**
Iron Reduction

- Reduces Fe$^{3+}$ to Fe$^{2+}$, and ... 
- Many iron reducers can utilize a variety of electron donors (organic and inorganic); e.g.
- *Geobacter metallireducens* – can be used for cleaning up petroleum spills and radioactive (i.e. uranium) contaminants.

http://www.geobacter.org/
And bacteria on and in other organisms . . .

Is more often than not a very good relationship!
Human health depends on bacteria!

As long as your immune system remains healthy, symbiotic bacteria help keep invaders out by competing for limited resources. They are useful — so useful, in fact, that we could not live without them.

They help humans digest food, mitigate disease, regulate fat storage, produce vitamins that we can’t make on our own, and even promote the formation of blood vessels.
### What Good Bacteria Do

Some things we know about good bacteria, besides the generalization that they help to counteract pathogens:

- **Good bacteria can break down certain foods, such as plant starches, that we cannot digest on our own.** “This enables us to extract more energy from what we consume,” says Jeffrey I. Gordon, director of the Center for Genome Sciences at Washington University School of Medicine in St. Louis. (Similarly, cows can digest cellulose thanks to the good bacteria that live in their rumens.)

- **Good bacteria promote the storage of energy as fat.** According to Gordon, this raises the possibility that “an individual’s predisposition to obesity or leanness may be partly determined by the composition of the microbes living in the gut.”

- **Good bacteria help shape our postnatal development.** For example, they help to form our intestinal blood vessels, through which we absorb nutrients.

- **Good bacteria synthesize vitamin K and other vitamins that we cannot generate on our own.** They break down carcinogens. They also may influence the metabolism of drugs.

- **Good bacteria increase the rate at which the cells of the intestinal lining renew themselves, ridding us of damaged cells that could bring on gastrointestinal cancer.**

- **The good bacteria that infants acquire from their mothers and from the general environment at birth “educate the newborns’ immune systems,” says Gordon.** “This appears to reduce allergic responses.”

- **Each human carries a different set of bacteria, and its composition varies along the length of the gut.** Some of these bacteria are permanent residents; others are transient “tourists,” just passing through.
In our human bodies...

One square inch of skin may be home to more than half a million bacteria.

Over 170 different types of bacteria live in our mouth; many help stave off the bad ones that contribute to bad breath and plaque on our teeth.

In 1 gram of colon, there is an estimated 100 billion bacterial cells; remember our feces is half microbes by weight.
More human body examples; not all good.

Much of the urinary system is normally sterile!
Some amazing facts!

- We each carry two to five pounds of live bacteria in our bodies (unless you’ve taken antibiotics)!
- An adult human has about 10 times more microbial cells than human cells; so based on cell number, each of us is 90% microbial and 10% human.
- Trillions upon trillions of microbes, representing some 1,000 species, are packed within us, especially in our guts. A single milliliter, about a gram, of the colon's contents might harbor 100 billion of them.
- The genomes of our gut microbes probably contain 100 times more genes than our own genome, providing us with traits we never developed on our own.

More on gut bacteria:

"I don't know what a human would look like without a colonized gut," said Chana Palmer, the lead author of a recent study. "The microbiota are important. They help you extract more from your food; they're important for the immune system; and they help protect us from being colonized [by other] microbes that are going to do us harm."

Before birth, the human intestinal tract is sterile, but babies immediately begin to acquire the microbial denizens of the gut from their environment — the birth canal, mothers' breast, and even the touch of a sibling or parent. Within days, a thriving microbial community is established and by adulthood, the human body typically has as many as ten times more microbial cells than human cells. This is primarily due to the large number of microorganisms that have taken up residence in the intestine.
In our gut good bacteria trigger protection proteins.

- Studies by Howard Hughes Medical Institute researchers indicate that the millions of symbiotic, beneficial bacteria living in the human gut may actually be helping to stave off injury to the lining of the intestines.

- "Until now, almost everything we knew about the benefits of commensal bacteria had to do with their biological activity. [We knew that] they metabolize nutrients to enable us to absorb them more readily. They aid in the early development of the gastrointestinal system. And they produce factors that prevent colonization by pathogenic bacteria. Our work, however, has revealed a role that is quite different."

- They discovered that beneficial bacteria also trigger proteins called Toll-like receptors (TLRs) to maintain the health of intestinal epithelial cells and to activate machinery that responds to injury.
Probiotics – supplementing the good guys.

* Using good bacteria to promote health, a practice sometimes called probiotics, has a long history, e.g. . . .

* Bulgarian and Russian peasants who eat lots of yogurt regularly live to ripe old ages.

* Yogurt contains live cultures of Lactobacilli, one of the better-known strains of good bacteria.

* The jury is still out on whether it really helps, but it certainly can’t hurt.
Bacteria are symbionts in lots of life!

Here’s a cool marine example: The squid-Vibrio symbiosis — Vibrio fischeri and Euprymna scolopes. Vibrio colonizes the light organ, which bioluminesces, camouflaging the squid at night against ‘moon glow.’

serc.carleton.edu/.../bobtailsquid.jpg
And the much espoused hydrothermal vent symbiosis . . .

The tube worms that colonize hydrothermal vents contain $10^9$ sulfur-oxidizing bacteria (Thiovulum) per worm.

- The tube worms trap O$_2$ and H$_2$S gases, which the symbiotic bacteria use for energy and nutrition.
- The tube worms use the waste products of the bacteria for nutrition.
- Not to mention the rest of the Archaea and Bacteria there that form the basis of the entire hydrothermal vent food chain!
Another marine example:

Epulopiscium spp. and surgeonfish symbionts:

- This is a very large bacterium, and it does not divide by typical binary fission; instead it . . .
- Uses internal reproduction, which seems to have evolved from endospore formation.
- It seems to help the fish digest its algae diet.
And yet another . . .

* Stilbonematinae nematodes and marine oligochaete . . .
* Are symbiotic with sulfur-oxidizing bacteria.
There’s an obligate symbiont in many insects too.

* These bacteria usually have reduced genomes, yet often a very large cell size.
* Usually they are a nutritional symbiont;
* But sometimes a protective symbiont.
* They’re often localized in specialized cells of the insect, as we see here in aphids.
Another insect bacterial symbiont . . .

*Homalodisca literata* and its bacterial symbionts
*Baumannia cicadellinicola* (gamma-Proteobacteria)
*Sulcia muelleri* (Bacteroidetes)

Bacteriome (organ containing symbionts) pulled out from abdomen

Photos by Phat Tran and Nancy Moran
And one that even...

- Influences reproduction and sex determination in its insect host!
- These are named *Wolbachia*, and are common in about 60% of all insects.
- Several species are so dependent on the symbiosis that they are unable to reproduce effectively without the bacteria.
- It works by killing or feminizing males, through cytoplasmic incompatibility, or by inducing female parthenogenesis!

So research is ongoing in using it as a mosquito control agent: [http://www.youtube.com/watch?v=Y2G1a2TdQ](http://www.youtube.com/watch?v=Y2G1a2TdQ)
Commercial applications are widespread. Production of foods, e.g. vinegar, sauerkraut, pickles, olives, yogurt, and cheese; manufacture of . . .

Vitamins, ethanol, and acetone. Plus . . .

Transgenic bacteria make recombinant proteins, e.g. insulin and blood-clotting factors.

Bacteria also make enzymes used in dishwashing and laundry detergents.

Water and waste treatment is a huge application. And . . .

Bioremediation – metabolize and detoxify pollutants – is increasingly important!
For example, petroleum biodegradation and production.

Hydrocarbon-oxidizing bacteria use hydrocarbons (e.g. oil) as electron donors and oxidize hydrocarbons to CO$_2$. Others can even ‘eat’ radioactive waste!

- Scientists are working on ways to put bacteria to work in recycling plastics.
- Thermophilic bacteria are being used to produce cellulosic ethanol.
- Bacteria are genetically altered to excrete ‘renewable petroleum.’
- Bacteria are modified to glow when they detect certain chemicals.
- Breweries are using bacteria to decrease impact on local water processing plants.
Next, we’ll look into the wild, wild world of . . .
The Archaea . . . even crazier, even more extreme, and just as ubiquitous as the bacteria, but, as far as we know, none of them cause any human disease!