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The Mathematical Garden

The hidden science and mathematics behind nature's beauty

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https://terpconnect.umd.edu/~toh/ScienceMathGarden.pdf

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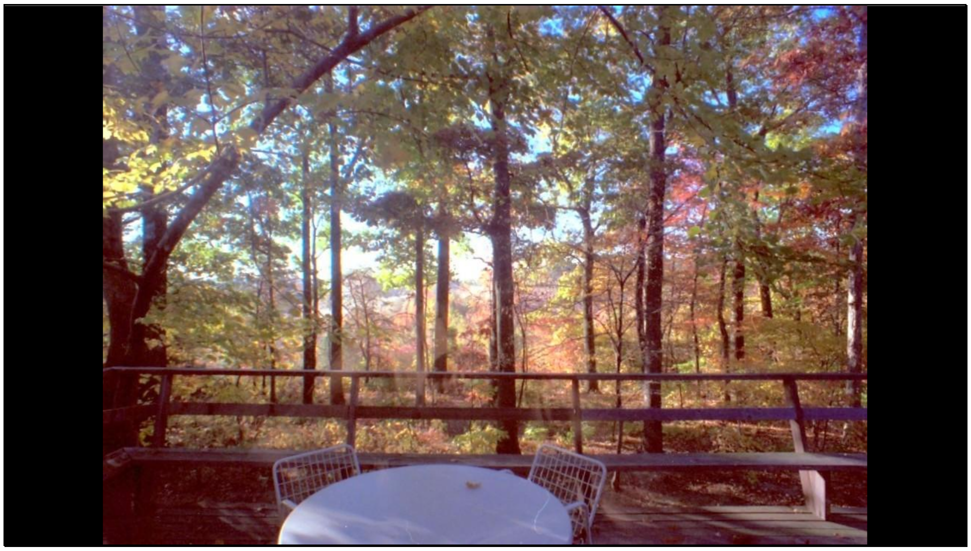

In 1981, my wife and I bought a house in eastern Silver Spring, near Cloverly. The yard (about 0.4 acres) was a wild hardwood forest, as shown in this photo. For years it was left unattended, but when we retired in 1999, we thought gardening would be a good active retirement hobby that we could share, and so we set out to landscape the property into an ornamental shade garden.

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My wife and I enjoy international travel and have seen many beautiful gardens around the world. Many were *formal* gardens, like the ones in these photos, in St. Petersburg, Russia, Versailles, France, and Jaipur, India. They are characterized by large open sunny spaces with neatly clipped hedges and symmetrical geometric features. They're intended to be impressive, and they do have a certain mathematical appeal, but our shady wooded lot in Maryland would be much more suited to an informal *woodland* garden design.

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We were more attracted to gardens with an Asian flair, such as Claude Monet's Garden in Giverny, France, or the Japanese gardens I had seen on business trips to Japan in the 1980s. These gardens usually have winding asymmetrical paths, water features, natural rock, weathered wood, moss, and Asian decorative features.

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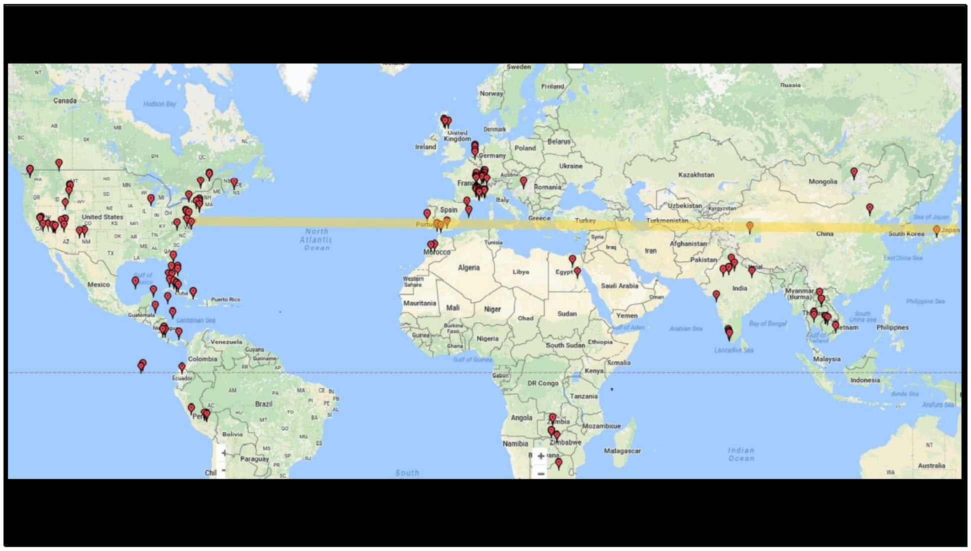

Fortunately, many of the beautiful plants and trees that are common in Asian gardens can be grown successfully in Maryland. In fact, you can see on this world map that the horizontal yellow line, marking the latitude of Maryland, passes through Turkey, central China, Korea, and Japan, so we should have a generally similar climate.

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Over the years we collected and planted shade-tolerant hardy plants that would form the backbone of the garden, with an emphasis on those that are of Japanese or Korean origin, such as Japanese maples, Painted fern, Rhododendron, Hosta, Toad lily, Andromeda, Fountain grass, Bamboo, Nandina, and Kousa dogwood. We get our plants from local nurseries, garden club events, swapping with friends and neighbors, and even from "volunteer" seedlings that sometime pop up in our garden, brought by the wind or the birds. These volunteers include Japanese maple, Kousa dogwood, wood poppy, woodruff, and fall-blooming clematis. Some, like Bamboo, painted fern, English ivy, toad lily and ground covers like will spread readily if given the chance but are easily contained *if you keep your eye on them*.

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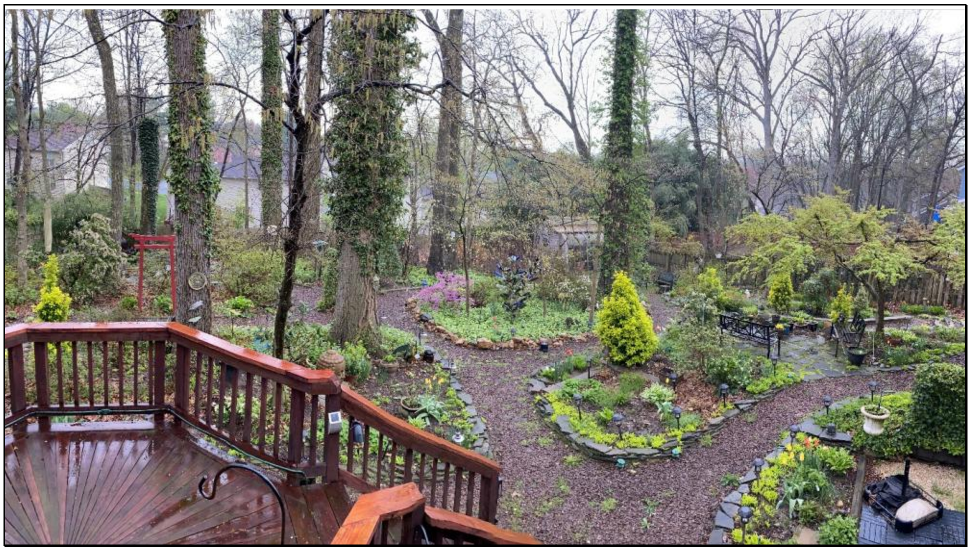

The property is on a gently sloping south-facing hillside. One of the principals of informal woodland garden design is that the garden paths should curve and wind so that you can't see the entire garden from any one vantage point, which invites you to explore. By the 2010's much of the path network in our garden was complete. This photo was taken in early spring, before the trees had leafed out, showing some of that branching path network, but some of it is obscured by trees and bushes. This is clearly not a formal garden plan.

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Here is the same photo, with all the paths marked up, showing even those in the background that are not clearly visible. We did all this work ourselves, one section at a time, over a span of 25 years, and counting.

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Here, we are constructing one of two goldfish ponds. That required moving soil to make a level area, constructing a retaining wall on the downhill side, digging a big hole for the pond, and removing the rocks and tree roots. We lined the hole with a pad and rubberized pool liner and covered the edges with small boulders and river rocks.

You can also see here the heavy red clay soil that we had to deal with. Soil like that would require the addition of lots of organic matter (e.g. compost) to make it ideal for gardening.

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We keep goldfish in the ponds all year; they are cold-blooded and survive the winters just fine, even if they are not fed and even if it freezes over. All winter long we have air bubblers running in the ponds to aerate the water and remove toxic gases like ammonia. Baby goldfish sometimes live for several years, enough to reach 5-6”. They breed in the ponds, producing scores of tiny fish.

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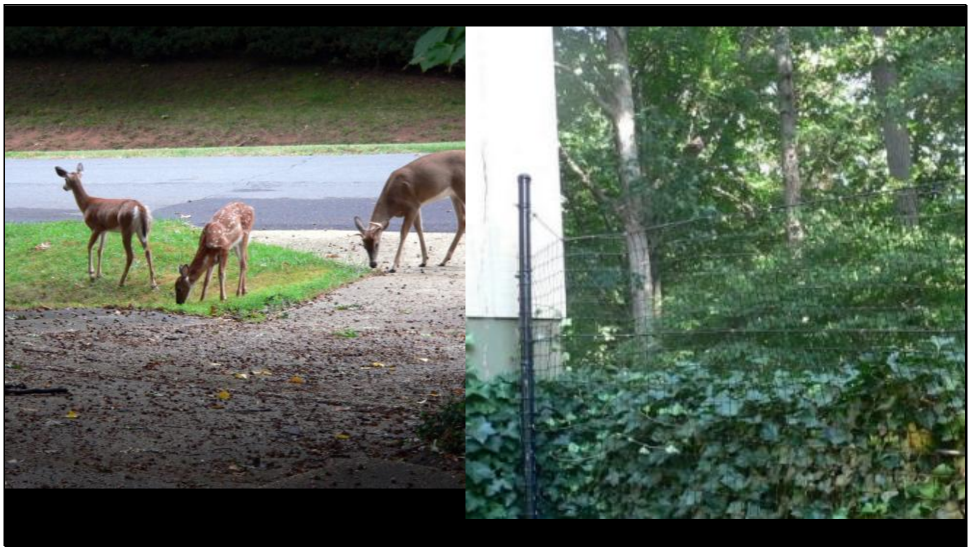

Deer can be a real problem. To keep them out of the main garden, we had an 8-foot-tall deer fence installed around the entire back garden in 2008, based on a recommendation from Brookside Gardens. It's designed to be inconspicuous, but if you look closely, you can just see it in the photo on the right.

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In time, the deer became so destructive to our azaleas, fancy hostas and hybrid daylilies that we eventually had to move over 100 plants into the area inside the deer fence, which we did over a period of several years. Outside the fence, we emphasize plants that deer don't like, such as Butterfly bush, Hellebore, Daffodils, Liriope, False Holly, Spirea, and Peony.

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Category	Definition	Lifespan	Growth Cycle	Examples
Annuals	Plants that complete their entire life cycle in one growing season	1 season (year or less)	Germinate → grow → flower → set seed → die	Marigolds, zinnias, wheat, corn
Biennials	Plants that take two years to complete their life cycle	2 years	Year 1: grow leaves/roots (rosette) Year 2: flower → set seed → die	Foxglove, parsley, carrots
Perennials	Plants that live for more than two years, flowering annually or intermittently	Several years to decades	Grow → bloom (many times) → may go dormant seasonally but do not die	Peonies, hostas, daylilies, helebore
Deciduous Woody Plants	Trees/shrubs that lose their leaves during part of the year	Many years (woody plants)	Go dormant seasonally, often to conserve water and survive cold or drought	Tupelo, oak, hydrangea
Evergreen Woody Plants	Trees/shrubs that retain leaves year-round	Many years (woody plants)	Shed old leaves gradually but always have foliage	Azaleas, holly, boxwood

Plants in ornamental gardens can be classified into several types. Perennials, biennials, annuals, and woody plants of two types: deciduous and evergreen.

Perennials die back to the ground in the winter, but the roots remain alive to emerge next spring.

Annuals die completely and must be replaced each year.

Woody plants like trees retain their stems and branches; deciduous ones lose their leaves, and evergreen ones keep them through the winter.

Biennial plants have a two-year life cycle. The first year after growing from seed, they do not bloom. After that growth winters over, the plants bloom the next year, and those blooms make seeds that fall to the soil and germinate, starting the process all over.

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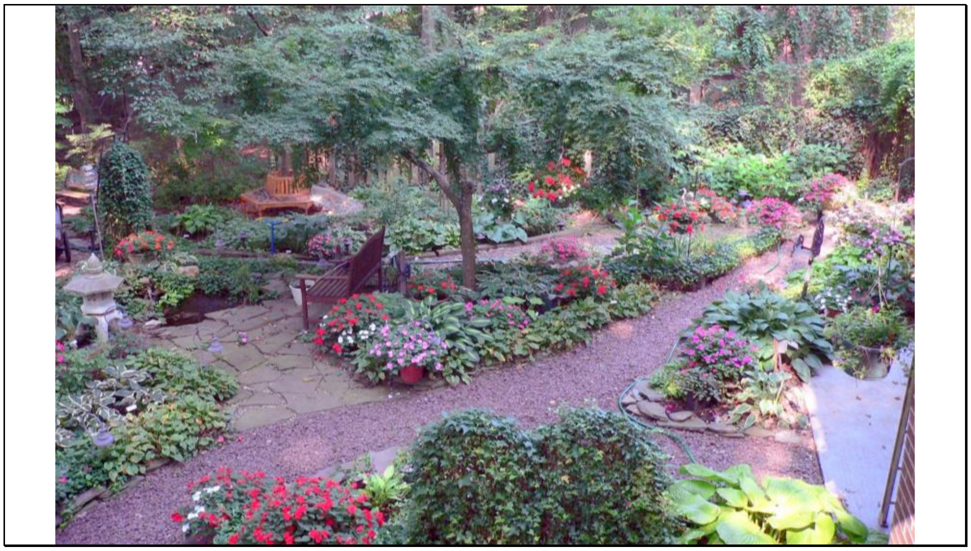

By combining perennials, woody plants, and annuals, you can have color somewhere in the garden all season.

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When we bought the house, there was a 2-foot-high retaining wall in the back yard made of stacked wooden railroad crossties. Creosote-treated railroad ties are a critical component of railway infrastructure, providing stability and support to the rails. Creosote is a tar-like substance derived from coal and petroleum. It forms a protective barrier that extends the lifespan of the ties. This has been a standard choice for railway construction since the mid-19th century due to their affordability, availability, and effectiveness in withstanding harsh weather conditions. We learned that crossties in the garden can last about 40 years.

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And sure enough, in 2015, about 40 years after their initial construction, the crossties began to rot, and the wall began to sink and slump several inches, as indicated by the level line in this photo. There was a danger that the whole wall might collapse. Crossties like this are too heavy for us to handle, so we had to cut them up using a chainsaw and dig them out.

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We replaced them with a wall made of trapezoidal prism "split face" stone blocks - about 40 pounds each – which are much easier for us to handle than crossties. These are factory-made blocks that are flat on 5 sides, for easy stacking, but with a rough random surface finish on the front facing side. They are manufactured by molding two blocks as one larger unit. After the concrete is only partly set, a machine splits them in two, creating two blocks with a natural looking random surface.

The trapezoidal shape makes it easy to build curved walls and rounded corners. We dry-stacked them, for better drainage, and reinforced the wall with vertical rebars in the interior cells that were filled with dry concrete mix, which hardens naturally in a few days.

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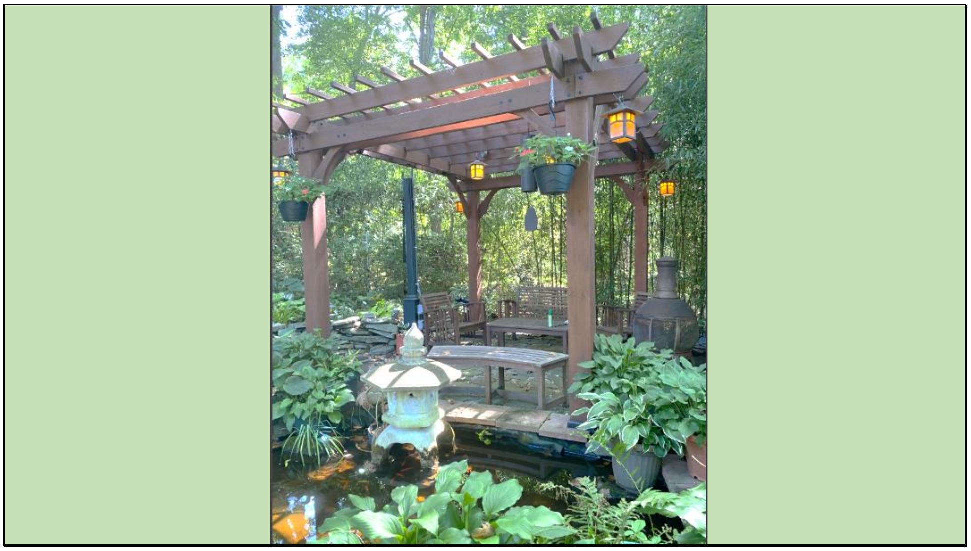

We built this pergola from a kit that we ordered online and built in 2020 during Covid. It was shipped to us as 75 pre-cut wood pieces, which we painted with preservative stain and bolted together with the supplied hardware, following the pictorial instructions. We placed it on the flagstone patio beside the lower pond and added the hanging lanterns. Behind it we planted a bamboo stand. Bamboo is a famously aggressive spreader if left unattended. However, it's easily contained: if new shoots pop up where they don't belong, just stomp on them or snap them off by hand.

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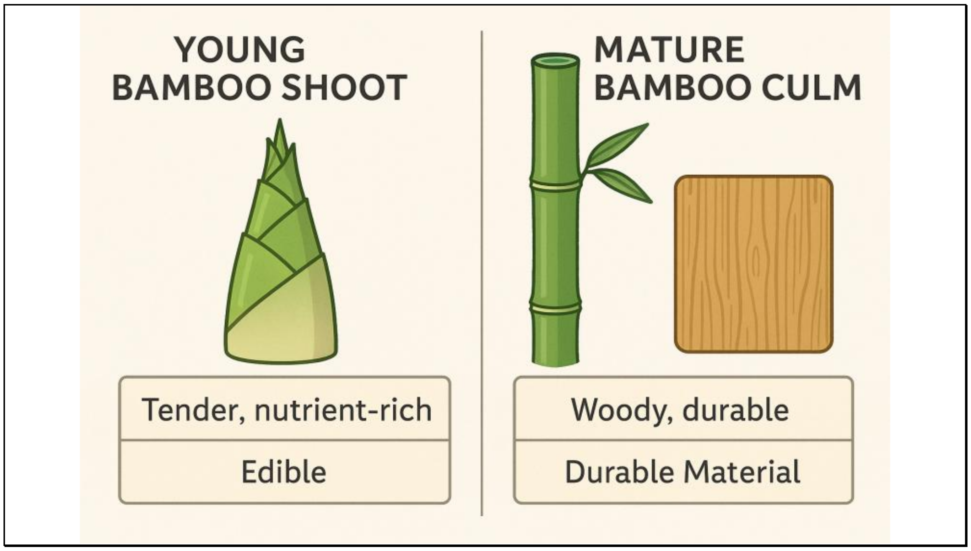

There's a big difference between young bamboo shoots and mature bamboo, and it's not just size. New shoots are soft and tender. At this stage, bamboo is low in lignin (the substance that gives wood rigidity), but rich in fiber, water, and nutrients, and are tender enough to cook and eat *after proper preparation* (boiling to remove the cyanogenic glycosides, which are naturally occurring toxins that protect plants against predators, including us humans.

After about 3–5 years, bamboo becomes very strong and stiff, with a tensile strength comparable to steel (hence, their use as scaffolding in Asian counties). It is rich in lignin and silica, making it hard, scratch-resistant, and (with treatment) moisture-resistant.

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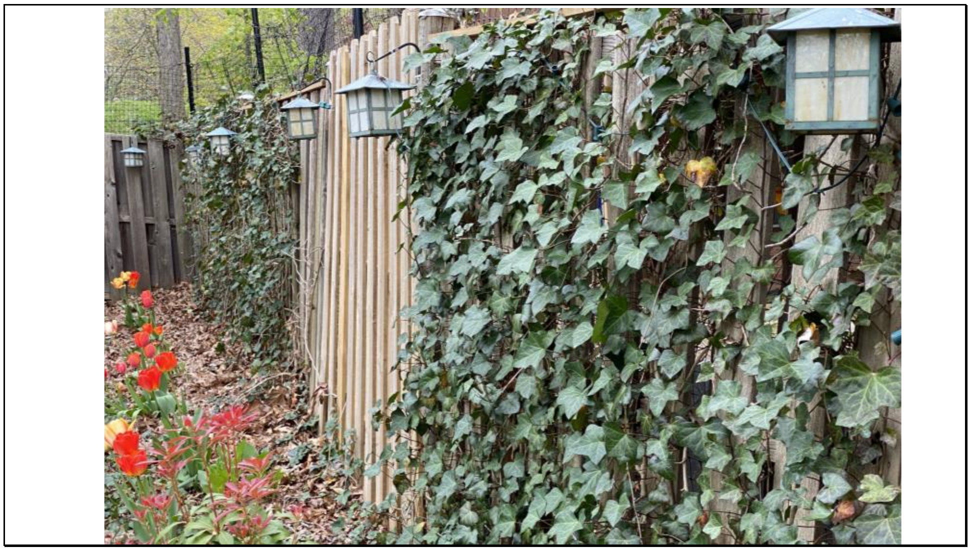

Early on, we decided to install exterior electricity with enclosed outlets throughout the garden to power the pumps, fountains, fans, decorative lighting, Bluetooth speakers, security cameras, and the greenhouse. 115-volt lines are run through tough waterproof underground conduits for safety, so if you hit one with your shovel while digging it's not a problem.

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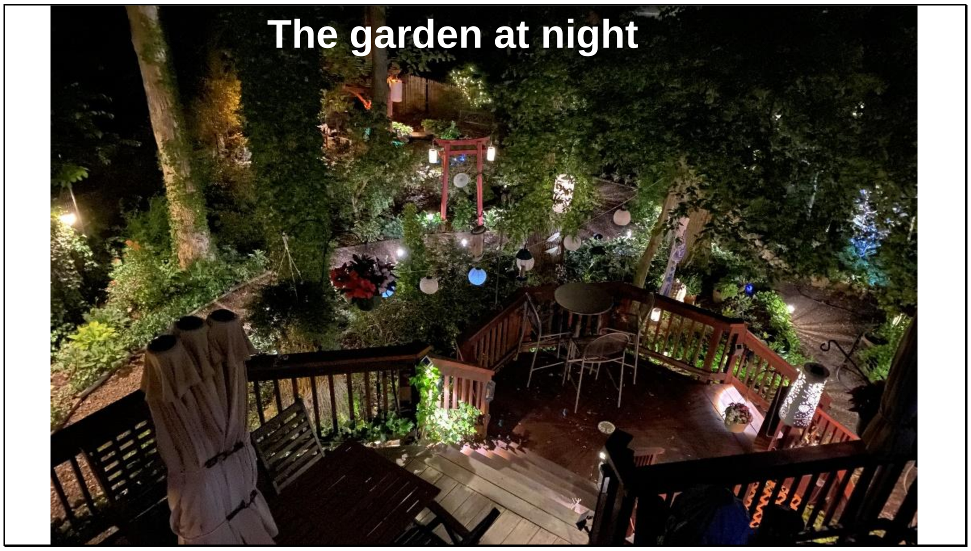

Exterior lighting is used throughout the garden, resulting in a striking look in the evenings. There are path lights, hanging lanterns, spotlights, and string lights.

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We use a combination of low-power LED and solar powered lights. These are all automated. As the daylight dims, photocell controllers turn on groups of lights automatically one by one and then turn them back off again after a set number of hours or when their rechargeable batteries are exhausted.

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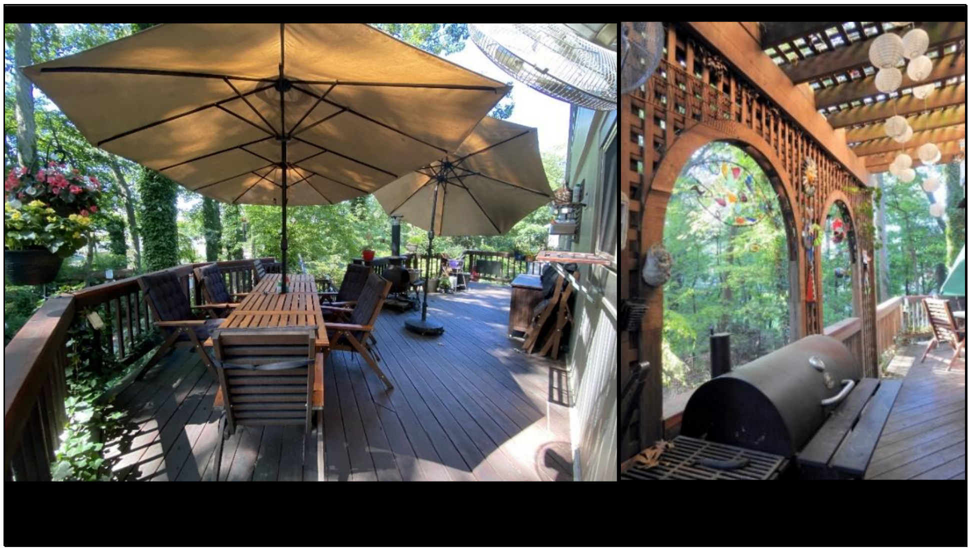

Our deck overlooks the garden. The main deck is one story above garden level, which has the advantage that there are fewer mosquitoes up there, because mosquitoes tend to stay close to the ground-level water sources where they hatch. We placed an outdoor dining table just outside the kitchen. Adjacent to that is a BBQ grill, just outside the kitchen sliding doors in a covered arbor, which is great when we want to grill in rainy weather.

But the kitchen, in addition to feeding our guests, also feeds the garden….

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In the back corner of the garden, we keep a large compost pile divided into two sections. This works over a two-year cycle. The raw material goes into the left section; this includes all plant clippings, fallen leaves, finished annuals, small twigs, fireplace ashes, and all kitchen scraps, except meat and citrus. We water it in dry periods and add a shovel-full of garden fertilizer once a year to feed the microorganisms and fungi that do the work. (Sticks and twigs larger than a little finger are saved as kindling for the fireplaces). Sometime in the middle of the summer, we move all that material over to the right side - top layer first, so the whole thing is inverted. There it continues to decay all through the next fall and winter. Any new material goes into the now-empty left-hand side.

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The next spring, the compost on the right side will be finished and ready to be harvested. Once all the finished compost on the right is harvested, the cycle begins again. Most everything is reduced to black crumbly compost after that two-year cycle. (Anything that is not completely composted is tossed back into the left-hand side). The finished compost is spread on the beds throughout the garden or used for the plants growing in pots.

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To complete the nutritional requirements of the garden, we apply a light application of a general-purpose inorganic fertilizer to all plants once a year in the spring. We use a battery-powered hand-held spreader to ensure even distribution. The numbers in the fertilizer are the percent of the major nutrients: Nitrogen, Phosphorous, and Potassium, but there are typically many more "micronutrients" in fertilizers, such as Iron, Manganese, Zinc, Copper, Boron, Molybdenum, Nickel that are needed in much smaller amounts.

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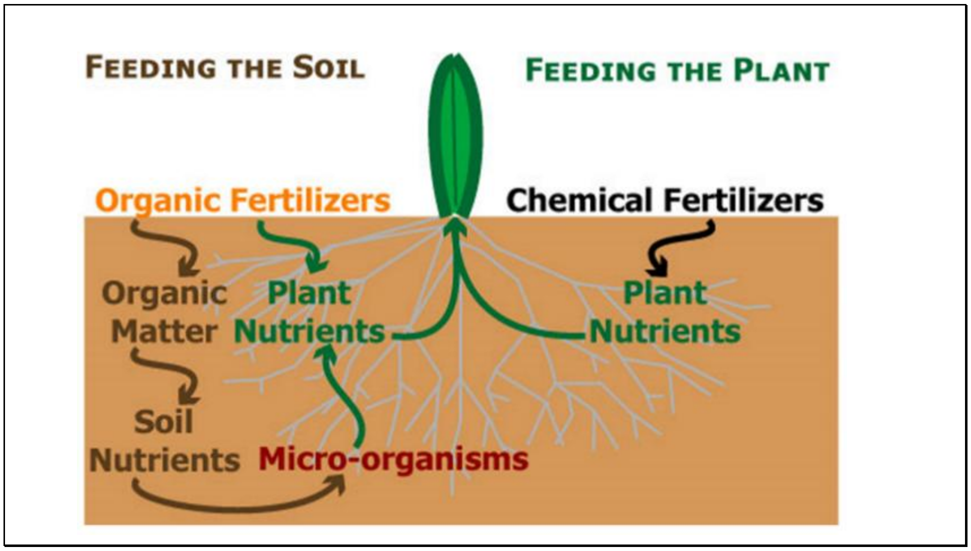

Feeding the soil versus feeding the plants. Adding compost to the soil improves its structure, adds organic matter, and supplies needed *micronutrients*, whereas chemical fertilizer just adds the required *macro* nutrients and does nothing for the soil structure. But, over time, the inorganic fertilizer is converted to *organic* material by plant growth. Eventually, all the plant clippings, fallen leaves, cut-down perennials and finished annuals are thrown onto the compost pile and are decomposed and returned to the soil after two years. In this way, the garden acts as an *inorganic-to-organic conversion system*.

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Compost eventually decomposes into *humus*, which is a dark, nutrient-rich, stable material that is resistant to further decomposition. It's a crucial component of healthy soil, contributing to its fertility as well as its structure. As a stable form of carbon, humus has a role in *carbon sequestration*. Most of the carbon contained in plant vegetative matter comes from soaking up carbon dioxide from the air, a process called "photosynthesis".

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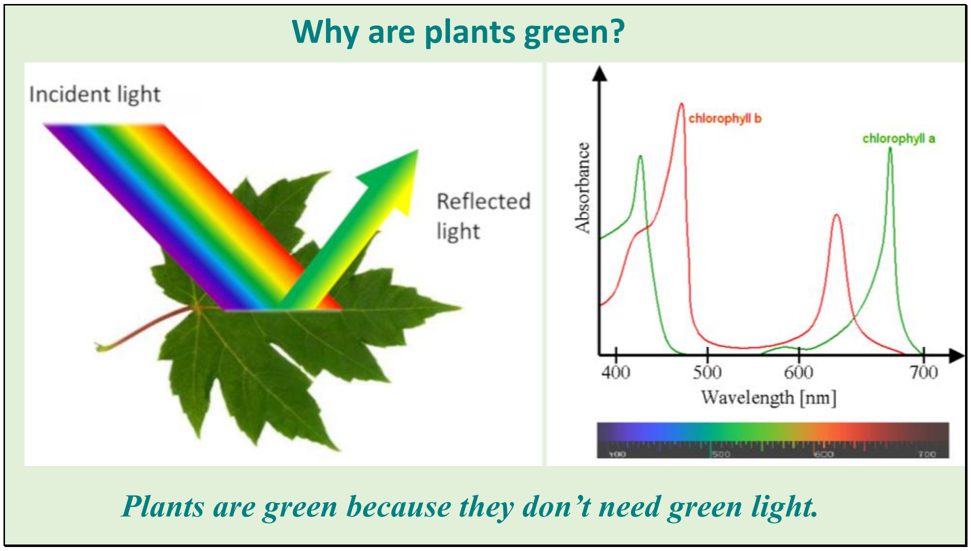

Chlorophyll is a green pigment in plant leaves that drives photosynthesis by absorbing the light that falls on plants. But it does not absorb all the light, only blue and red light. Chlorophyll does not absorb green light, so the plants reflect that light back, which is why they appear green. In other words, *plants are green because they don’t need green light.*

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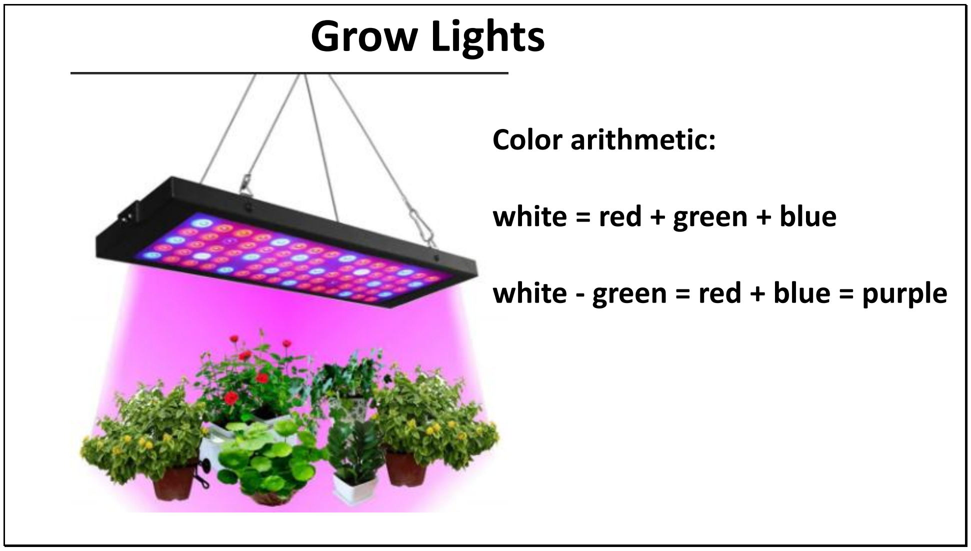

When plants are grown under artificial LED grow-lights, it is generally more energy efficient to use only blue and red LEDs, which makes the light look purple.

(In color arithmetic,
white = red + green + blue
Thus white - green = red + blue = purple).

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Photosynthesis

"Photo" = Light

"Synthesis" = Combining parts to form a whole

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{light + chlorophyll}} C_6H_{12}O_6 + 6\ O_2$$

Carbon dioxide	Water	Sugar (glucose)	Oxygen

Here is a highly simplified chemical equation for photosynthesis of sugar. The process captures the carbon from carbon dioxide, CO_2. The CO_2 comes from the air, the H_2O from the soil, and the light from the sun. The sugar produced goes to the leaves, fruit, and roots, where it becomes an energy store and a building block for creating cellulose, lignin, and other essential molecules plants need. The oxygen is essentially a "waste product" and is released into the air (because plants do not need that much oxygen to make a sugar). Lucky for us.

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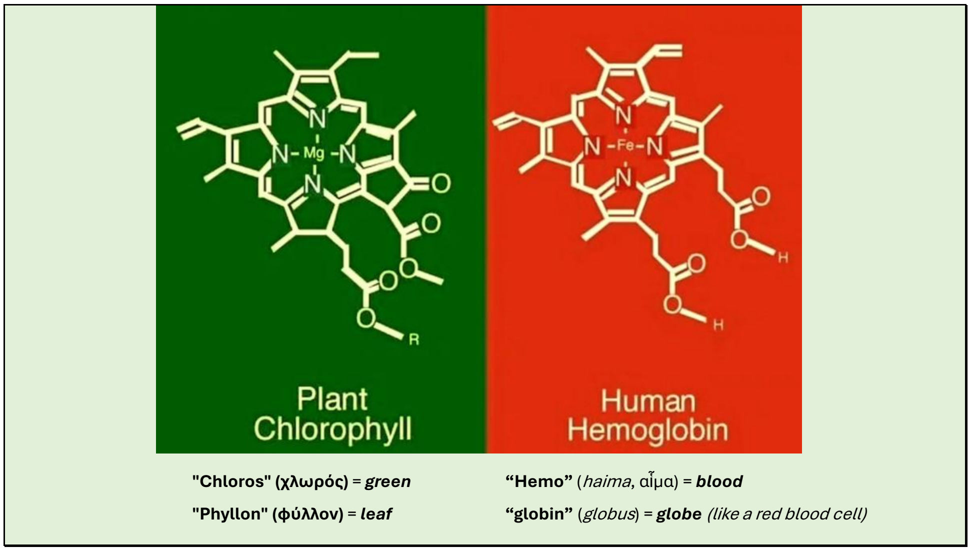

Here’s a curious science factoid. These are the chemical structures of Chlorophyl, on the left, and human Hemoglobin, on the right. Notice any similarity? How could this be? This is likely evidence of a shared evolutionary origin, when the precursors of plants and animals diverged into two branches about 1.5 billion years ago. But there is an important difference: in the middle, where Chlorophyl has Magnesium (Mg), Hemoglobin has Iron (Fe). Those are both essential to their functions – absorbing light and transporting oxygen, respectively. If a plant gets too little Magnesium (Mg) in its soil, its leaves turn yellow, which is called “chlorosis”. If we humans get too little iron (Fe) in our diet, we become anemic.

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One question that visitors to our garden often ask is: how do we keep ahead of the weeds? The answer is: a combination of (a) applying mulch to the beds each spring, (b) using groundcovers such as Lamium, Pachysandra, Lily of the valley, and Ivy in some areas, (c) using a pre-emergent weed preventer like *Preen*, and (d) hand-pulling the few weeds that escape those measures.

Each year in the spring, we apply a 2-inch layer of shredded hardwood mulch to the beds. The mulch eventually decays into the soil over the next winter, improving its structure and adding organic matter year after year. This takes about 30-40 bags of mulch each year.

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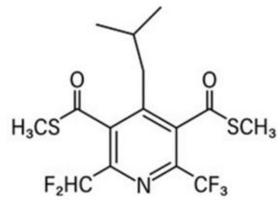
What about the weeds?



dithiopyr

A pre-emergent weed preventer works chemically, not by killing growing weeds, but rather by *preventing weed seeds from germinating* by disrupting key biological processes in the germinating seedlings. This is effective only for *annual* weeds that die each winter and grow back from seeds left in the soil. It does not work for perennial weeds whose roots survive the winters, such as dandelion and wild onion. You can't use a germination suppressor on areas where biennials grow. Those weeds can be controlled by spot spraying with a selective weed killer such as *Weed-B-Gon*, which will not harm grasses.

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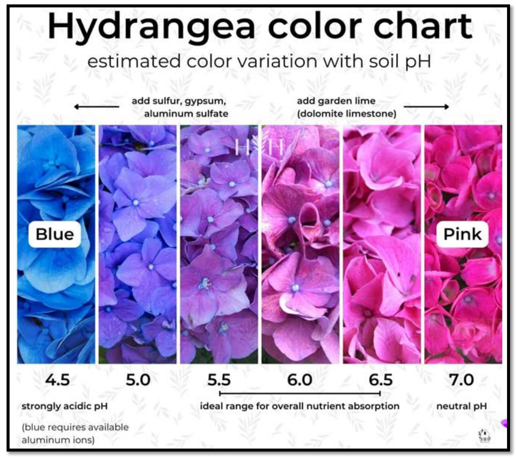
Blue Billows Hydrangea



Northeastern states often have acidic soil, particularly in forested areas. Plants favoring slightly acidic soils include rhododendrons and azaleas, blueberry, camellias, pine trees, magnolias, which often do well in our area. The color of hydrangeas blooms is particularly susceptible to soil pH: neutral or alkaline soils result in pink bloom, and distinctly acid soils result in blue blooms. You can apply limestone to the soil to make it more alkaline and aluminum sulphate to make it more acid. Both are available in gardens centers.

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To keep the water in the ponds aerated and to reduce the mosquitoes, we keep the water moving. This waterfall is created by an underwater pump that sucks up the pond water, filters it, and dumps it over the moss-covered rocks. We also place "mosquito dunks" in the ponds each month. These are small floating pucks that contain a bacillus called "Bti", a naturally occurring bacterium found in soil. It specifically targets mosquito larvae, as well as the larvae of black flies and fungus gnats, without harming other wildlife.

The moss on the rocks does not have to be planted; it just shows up all by itself in areas that remain moist over time.

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To help us relax after a hard day of gardening, we added a hot tub with a view of the garden, close to the walk-out basement sliding doors. Here's Mary, looking relaxed. Before leaving for Florida in the fall, we empty it, dry it and roll it into the basement.

Of course, it is important to pay attention to the chemistry of the spa water, such as pH and chlorine and such, which is right up my alley.

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Test strips are an easy way to test spa water quality. These are paper strips with several square segments, each impregnated with a different indicator chemical that reacts with a specific species in the water to produce a range of shades of color depending on the concentration of that species. You simply dip the strip in the water and compare it to the chart. You might be familiar with litmus paper, which is used a test for acidity or alkalinity.

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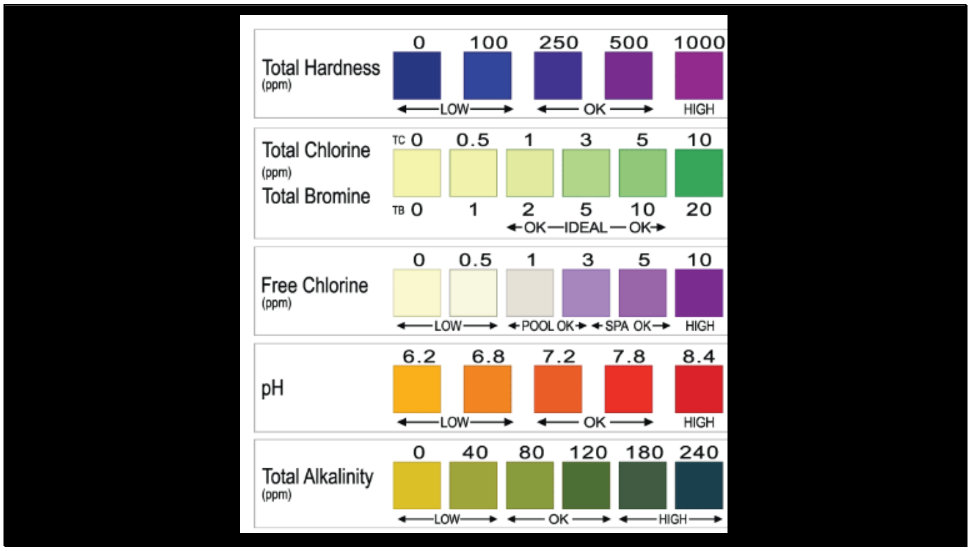

I use commercially available test strips that measure water hardness, chlorine, pH, and alkalinity. For each, the ideal range is indicated on the accompanying chart by the "OK". If the readings are out of range, I use sets of chemicals that are conveniently bottled and labeled for adjusting pH, chlorine, and alkalinity.

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Occasionally one of our big oak trees dies, perhaps from stress related to high temperatures or uneven rain, or it develops a disease, and we must have it removed by an arborist. We always try to estimate their age by counting the growth rings. Based on ring counts, our big trees are about 150 years old, which means that they started life (as an acorn) in about 1874, when Ulysses S. Grant was president!

Importantly, the removal of those big trees changes the pattern of sun and shade, forcing us to relocate some plants to other parts of the garden. A gardener's work is never done.

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Mathematical patterns are deeply embedded in the natural world. Even in an informal woodland garden such as ours there are many elements that reflect the underlying role of science and mathematics. For example, in our garden, you can find examples of simple geometrical shapes such as cones, spheres, octagons, and circles.

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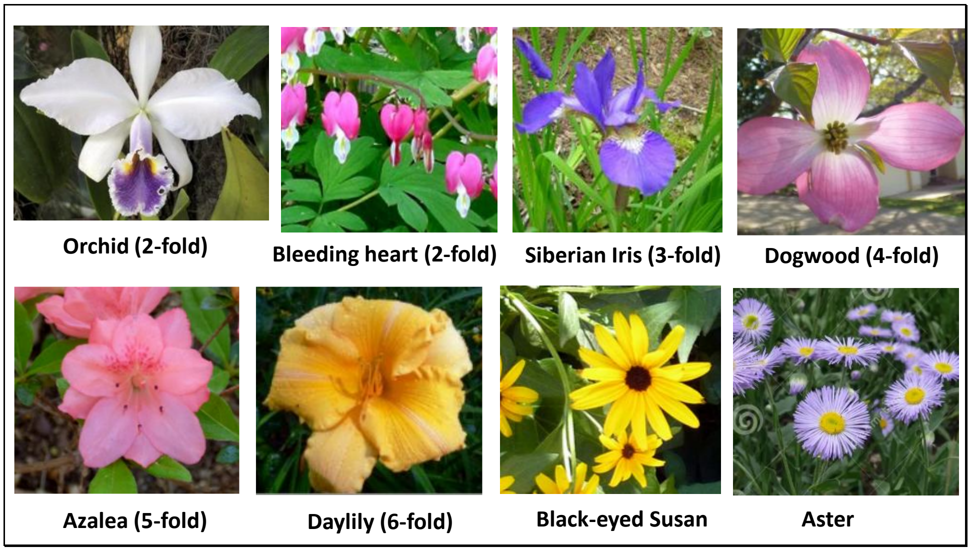

Many flowers exhibit symmetry, most commonly some form of radial symmetry. Most flower have a fixed number of petals, but Black-eyed Susans and Asters have variable number of petal-like "ray florets". Symmetry can result from genetic and developmental constraints that favor repeating structures. ***Why make a different gene for each petal when you can just re-use one that already works?***

Symmetry plays a role in pollinator guidance. Bees have been shown to have preferences for symmetrical patterns. Symmetrical shapes act like ***visual landing pads*****, helping pollinators locate nectar and pollen efficiently and ensuring that the pollen is deposited onto the optimal place. Bilateral symmetry often guides the pollinator to land in a specific way that ensures contact with reproductive organs. (In the** ***animal*** **kingdom, bilateral symmetry is overwhelmingly favored, with only a few exceptions: jellyfish, starfish, and sponges).**

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Even the structures and decorative object in the garden exhibit symmetry, such as a Buddha head and a pagoda that we found at garden centers, a torii that I built from plans found on the internet and painted red, and a pergola that we built from a kit.

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The lower section of our deck is an *octagon* with a "sunburst" radial flooring design. The carpenter had to measure and make 72 carefully calibrated pieces for this to work. (8 sides x 9 pieces per side).

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Manmade repeated elements with regular spacing contrast to the random asymmetry of most of the garden.

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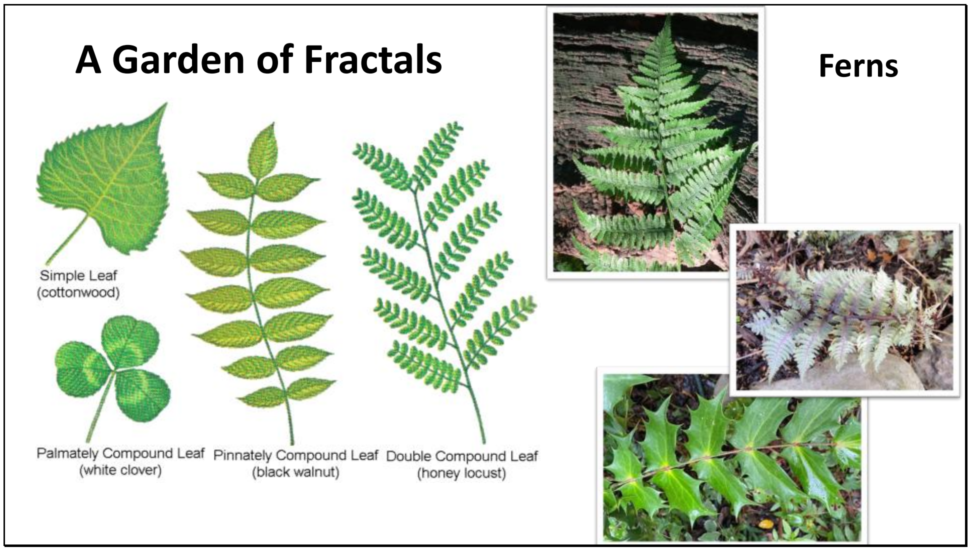

Fractals are complex geometric shapes that are known for their intricate patterns and structures that appear similar at any scale, meaning if you zoom in on a part of a fractal, you'll find it looks like the overall shape. Ferns are typical examples of plants that exhibit fractal patterns.

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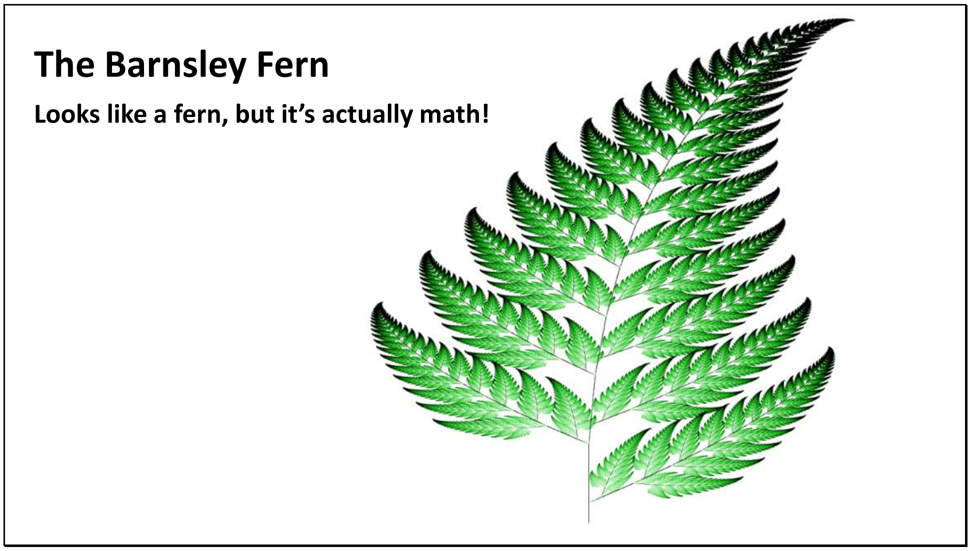

The structure of ferns has a surprising mathematical connection. A "Barnsley Fern", pictured here, is not a biological plant; rather it is a specific type of fractal graphic that *looks* very much like a natural fern. It's named after mathematician Michael Barnsley who first described it. This is a good example of how mathematical principles can model complex natural shapes. The structure shown here is generated completely by a surprisingly short computer algorithm.

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```
numPoints = 10000000;
x = zeros(numPoints, 1);
y = zeros(numPoints, 1);
for n = 2:numPoints
    r = rand;
    if r < 0.01
        x(n) = 0;
        y(n) = 0.16*y(n-1);
    elseif r < 0.86
        x(n) = 0.85*x(n-1) + 0.04*y(n-1);
        y(n) = -0.04*x(n-1) + 0.85*y(n-1) + 1.6;
    elseif r < 0.93
        x(n) = 0.2*x(n-1) - 0.26*y(n-1);
        y(n) = 0.23*x(n-1) + 0.22*y(n-1) + 1.6;
    else
        x(n) = -0.15*x(n-1) + 0.28*y(n-1);
        y(n) = 0.26*x(n-1) + 0.24*y(n-1) + 0.44;
    end
end
scatter(x, y, 1, 'g')
```

The Barnsley fractal algorithm shown here creates a fern-like graphic with only 20-some lines of Matlab or Python code. Here's the code that generated that graphic. Creating a Barnsley Fern is a common task in computer programming and graphics design classes, when teaching abstract computer-science concepts such as recursion, coordinate transformations, and probabilistic algorithms.

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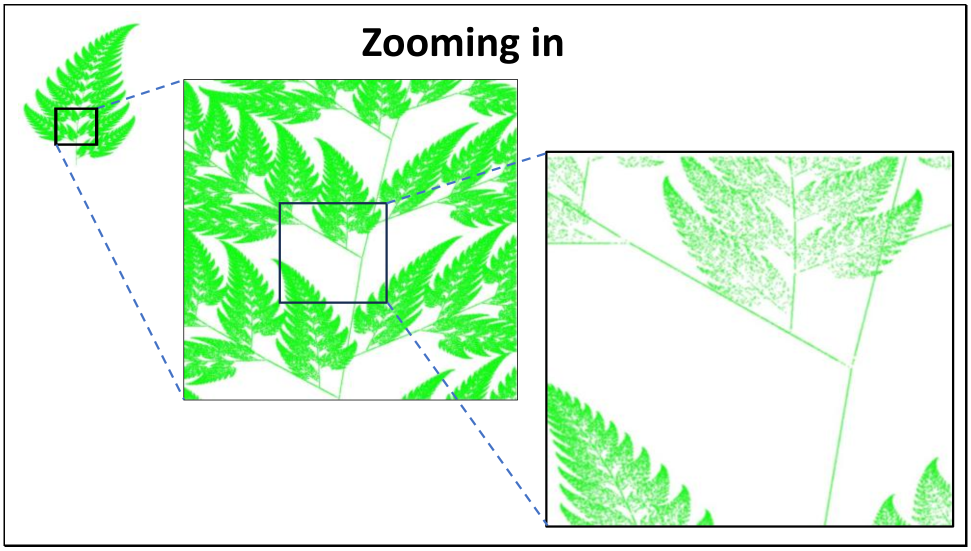

These three images show three different stages of zooming in to that computer-generated Barnsley fern graphic. As you zoom in, you can see that it is formed of millions of tiny individual dots (10 million in this example). (An ordinary computer can generate and plot the points at the rate of about 1 million per second). Of course, this is not the way that the plant actually grows; rather, it simply suggests some underlying similarity to the way that the gene expression and protein assembly work in developing ferns.

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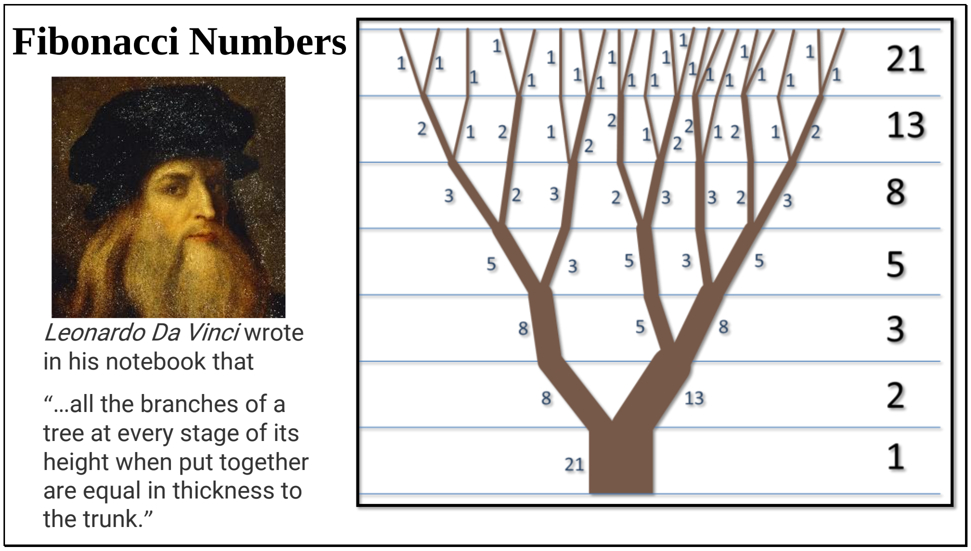

The integer sequence in which each number is the sum of the two preceding ones is called a "Fibonacci" sequence. The name comes from *Leonardo Bonacci*, an Italian mathematician from the Republic of Pisa. The first mention of the sequence appears quite early, in 1202, where it was used to describe the growth of rabbit populations. Hundreds of years later, Leonardo Da Vinci noticed a connection to the growth of plants.

In many trees, the branching pattern approximately follows a Fibonacci sequence. For example, a tree might produce one branch, then two, then three, then five, then eight, and so on. In the branching tree structure shown here, as the *number* of branches increases going up the tree, the *widths* of the branches proportionally decrease. Logically, the distribution of water and sap from the roots to the upper branches would require thicker branches below.

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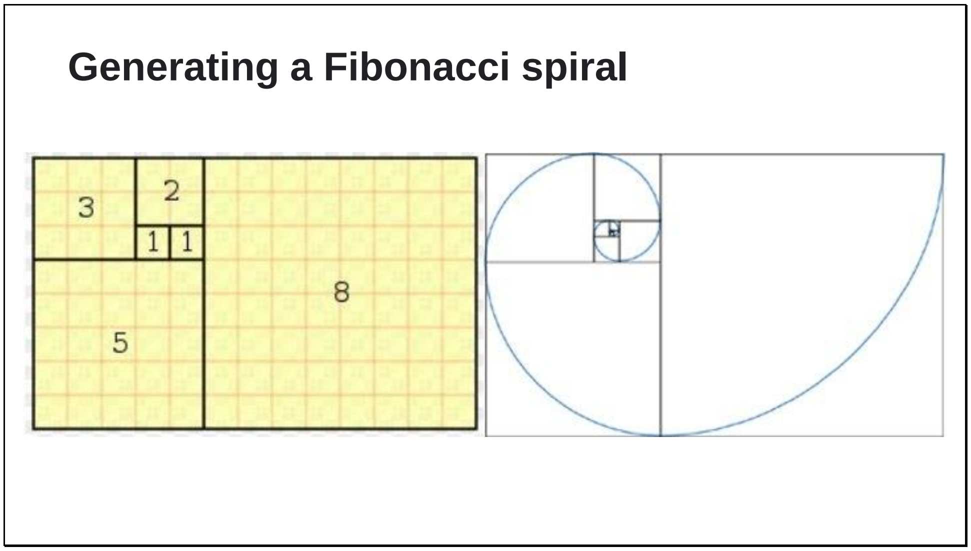

If you divide a rectangle into squares whose sides are in a Fibonacci sequence, and then draw a line starting in the right bottom corner of the rectangle within the first square and then touch the outside corner of each succeeding square, you will create a kind of spiral called a Fibonacci *spiral*. You can spot instances of Fibonacci behavior by studying the way various plants grow. Many seed heads, pinecones, fruits, vegetables, and even some seashells, display spiral patterns that when counted express Fibonacci numbers.

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The Fibonacci spiral occurs surprisingly often in nature. For example, you can spot instances of Fibonacci behavior by studying the way various plants grow. Many seed heads, pinecones, fruits and vegetables, snails, some seashells, and even hurricanes and spiral galaxies display similar patterns that express Fibonacci numbers.

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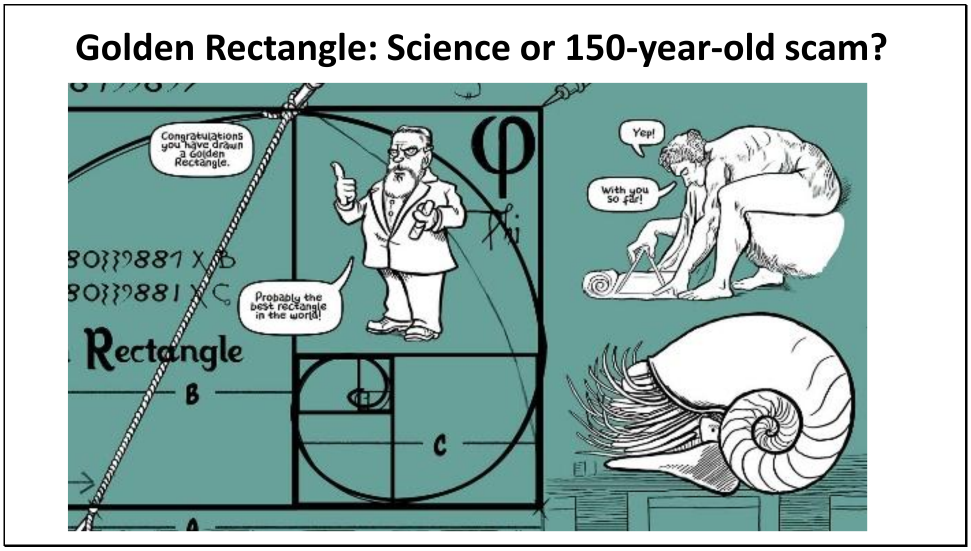

The *Golden Rectangle* is a rectangle in which the ratio of its length to its width is 1.618, the so called the Golden Ratio. Many believe that this is one of the most visually pleasing of all geometric shapes. It shows up more than you might expect in architecture and graphic art. But could that just as easily be an example of “confirmation bias”? Confirmation bias is a cognitive bias that causes people to favor information that *confirms* their existing beliefs or hypotheses, while disregarding or minimizing evidence that *contradicts* them. It's a common and natural human tendency, but it can lead to flawed conclusions if not consciously checked. Probably, there are at least as many rectangles in architecture and graphic art that do *not* conform to the Golden ratio as those that *do*.

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Even so, you can easily find examples. Here are two examples of structures in our garden that, apparently, do follow the golden rectangle rule. The brighter rectangular areas superimposed on these pictures are exactly Golden Rectangles. They do seem to match the proportions of the pictured items reasonably well. But when I made the Torii, shown on the left, I did not purposely build it with the Golden ratio in mind. And did the carpenter who built our arbor, shown on the right, make those arches conform to that ratio? Maybe.

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Here's another example, from a 1000-year-old Inca temple that we saw near Cusco, Peru. Did the Inca know about the Golden ratio? Or did I simply look through our photos until I found something that matched it pretty closely and ignore those that did not? You can decide for yourself by Googling "Golden ratio scam".

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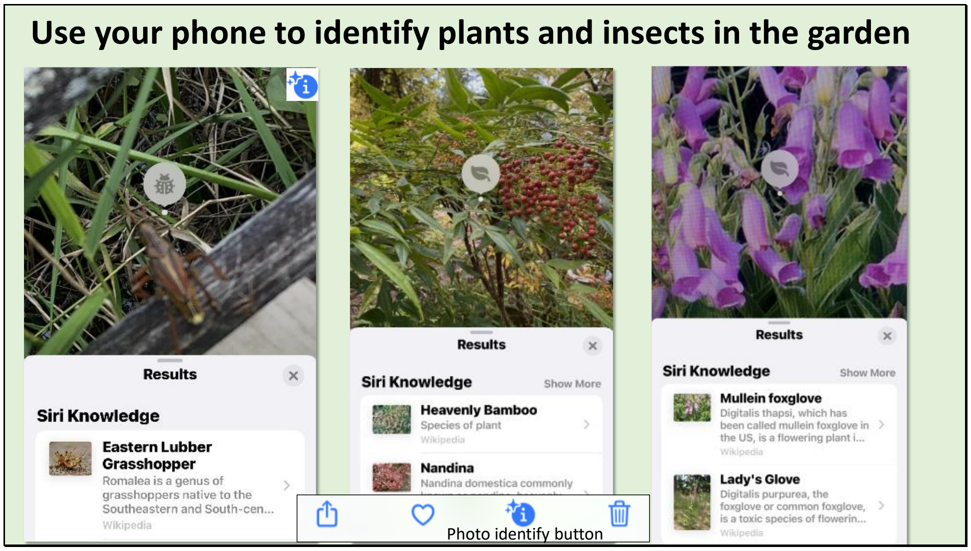

Technology can be a big help to the gardener. Smartphone picture apps often have an “identify” button that can identify items in a photo. For gardening purposes, it can identify many common plants and animals, including insects, such as the “Eastern Lubber” grasshopper shown on the left. In the middle example it identifies a plant and gives both the common name (e.g. Heavenly Bamboo) and the botanical name (Nandina). In the right-hand example, it identifies a foxglove and warns that this is a toxic plant. (The botanical name, “digitalis”, is also the name of a powerful heart medication derived from that plant).

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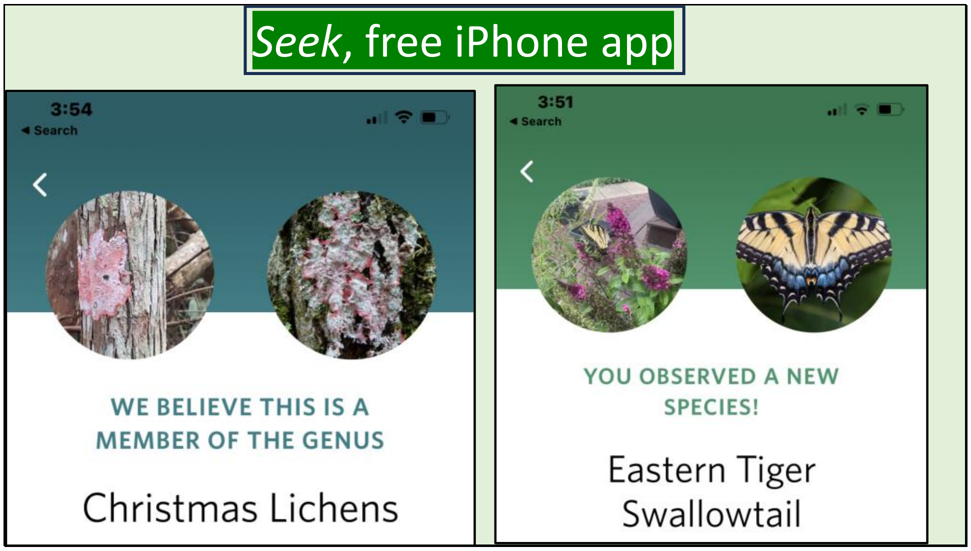

There is also a free app named "*Seek*" that is similar, except that you don't have to snap a photo – just point the camera at the item. In these examples it has identified the particular species of a lichen and of a butterfly.

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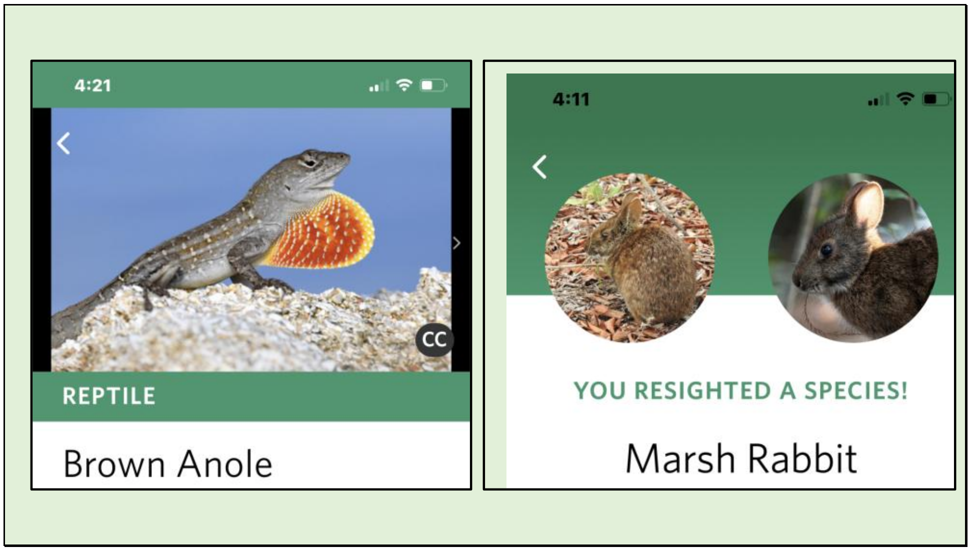

Here, it is identifying a species of a lizard and a rabbit.

These apps are great for identifying unknown seedlings that can pop up in your garden or even for identifying one of your own plants whose name you have forgotten.

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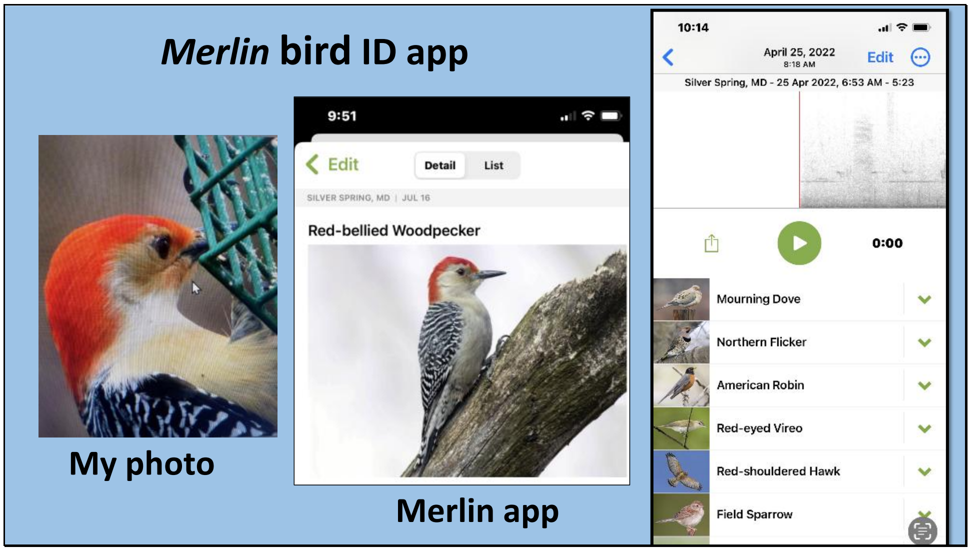

Another great app that we love is the *Merlin* bird ID app, from Cornell University's ornithology program. Just take a picture, or select that photo that you've previously taken, as shown here for this very colorful woodpecker visiting our suet feeder, which it identifies as a Red-bellied Woodpecker.

Merlyn can even identify birds from their *calls and songs*, which is especially useful since we usually *hear* more birds than we *see*. Each bird call that it identifies is listed on the screen as it hears it, along with a picture, and it highlights the bird again every time it calls. It also *knows where you are* (from your GPS coordinates) and looks ups birds in that particular area. If you travel to other parts of the world, you just download the bird song data from those areas. It's free.

All these apps are free and can be downloaded from the app store.

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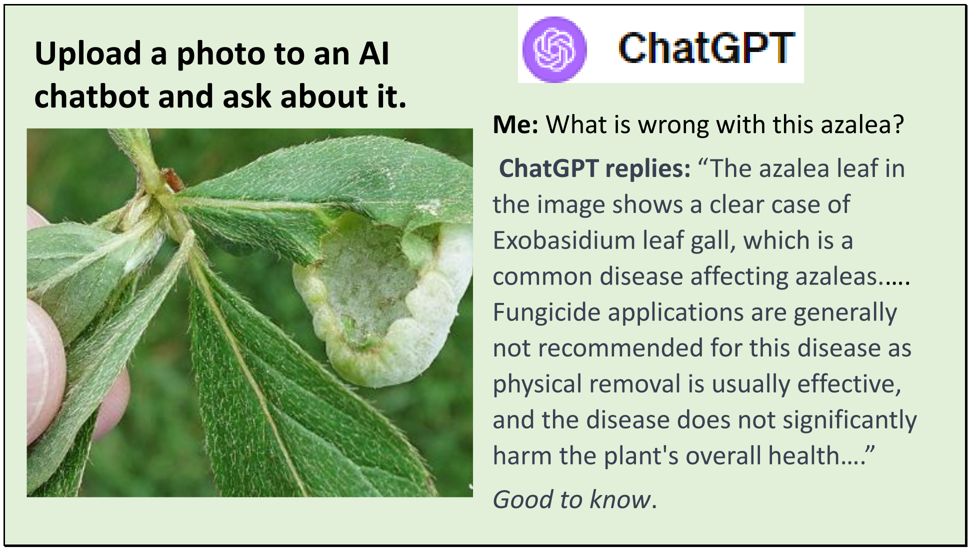

Popular chatbots such as ChatGPT can be a quick way to get specific answers to many garden questions. You can even paste photos and ask questions. For example, I pasted this photo of a strange growth on one of our azaleas and asked ChatGPT: “What is wrong with this azalea?”

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Many authors have claimed that gardening offers a range of health benefits, for physical, mental, and emotional well-being. – not only *physical* exercise but also mental health benefits such as *stress reduction*. Gardening is a holistic activity that provides a sense of accomplishment and a connection to nature. The author and physician Oliver Sacks wrote that "In forty years of medical practice, I have found only two types of non-pharmaceutical neurological 'therapy' to be vitally important: … *music* and *gardens*. (I agree, which is why I have an exterior Bluetooth speaker in the garden, next to the hot tub).

Personally, we find that gardening's greatest benefits is that it encourages patience and long-term thinking, because there's always something to look forward to in the next growing season.

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Thank you!

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https://terpconnect.umd.edu/~toh/ScienceMathGarden.pdf