Botanical Spirals:

...getting all twisted up in plant parts

Conducted by:

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Let’s pick a weed and draw its portrait.

The aster we see at the right seemed a likely subject. It has pretty purple flowers with bright yellow centers — allurements which at first compelled our attention.

Our aim is to make a drawing of that plant that looks like a real living, breathing, individual with its own personality. This is also a consideration familiar to artists who draw people: not only must a portrait artist capture the exact proportions and relationships of each feature of the subject, the artist must also bring to his task a knowledge of human anatomy, and this knowledge guides his pencil at every stroke. Similarly, the plant portrait painter must know his plant anatomy.

And so to work: we set up our specimen for drawing, following the guidelines for any sort of exact scientific illustration. We prop the plant up against a grid in order to get an idea of its proportions, very much like posing suspects in front of a height scale in a police lineup.

Using the grid to “eyeball” the plant, we’re able to plot approximately where the flowers appear on the stem, and where most of the leaves arise upon it, and other items of interest. For instance, what angles the leaves make with the stem, the length of the leaves, the size of the leaves, thicknesses, “attitudes” of curvature, etc.

Ten minutes of plotting and sketching, we guarantee you, will make you bleary-eyed and rather irritable. When you are drawing the leaves, you come across this problem: they’re not neatly arranged on the stem! They seem to sprout up every which way. Some point east-west; some north-south; the rest appear to be oriented arbitrarily in every direction in between.

Not only that, but despite the grid, we keep losing our place along the “forest” of the stem. Do I really have to draw every single wretched leaf? And I haven’t really got to the ruddy FLOWERS yet!

You can try the grid method, the “draw the negative spaces” method, the contour method, or anything else, but unless we use the same approach that portrait artists use —a knowledge of anatomy— we’ll probably stay lost among all those leaves.

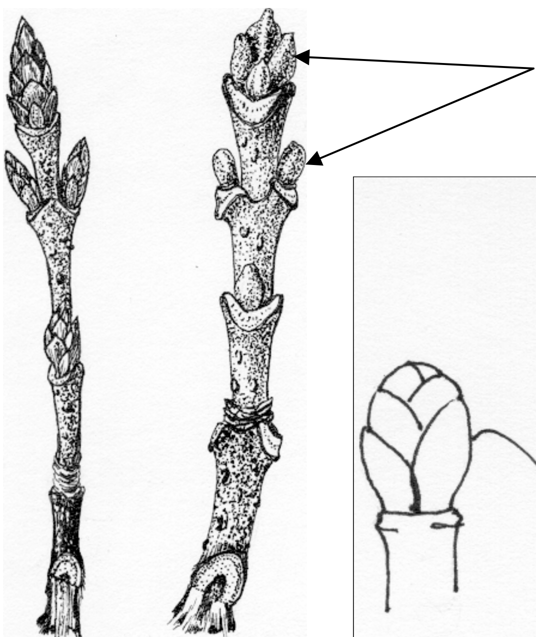
So let’s find out a little about how plants are put together...

How do plants grow?......*mostly in circles!*

Early March is a good time to get a preview of this Summer's foliage. Although the branches of trees and shrubs have no leaves, you may see for yourself that this Summer's leafy twigs have already arrived! They are stored in a compact container, packed very carefully. The packing has scrunched an entire leafy branch into a tiny, waterproof object marked "Do not activate until Spring." Nature's Shipping Department, always very efficient, puts these packages together ahead of time. Even in Winter, you can see next Spring's leafy twigs in the form of **buds**.

It is said that August is the time when Nature goes on vacation. It seems so, since fruits have already been produced and distributed, leaves have done their job of producing food for the plant through a long, productive growing season, and these worn-out leaves, chewed by insects and battered by summer storms, are already trying on their Autumn colors here and there. Nothing much seems to be happening in the plant world. In fact, the plant's job for the summer is not quite done. Most of the plant's energy in August and September is focused on forming next year's leaves and twigs. All the basic structures are completed at this time, and are stored as buds along and at the end of twigs.

A bud is next year's leafy twig.



Each bud, produced in late Summer, will grow into a leafy twig in the Spring.

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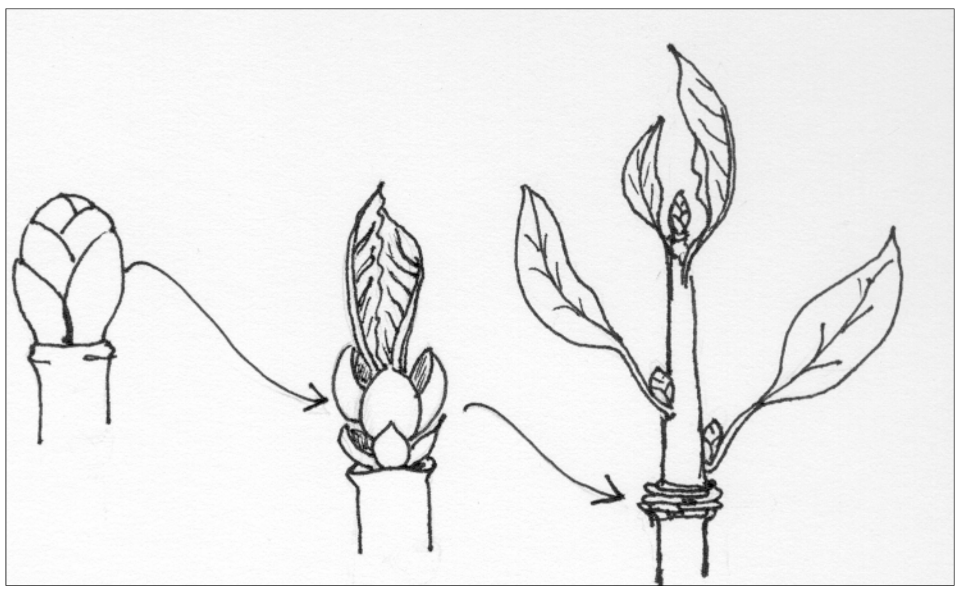

In Spring, the bud opens to form this year's leafy twig

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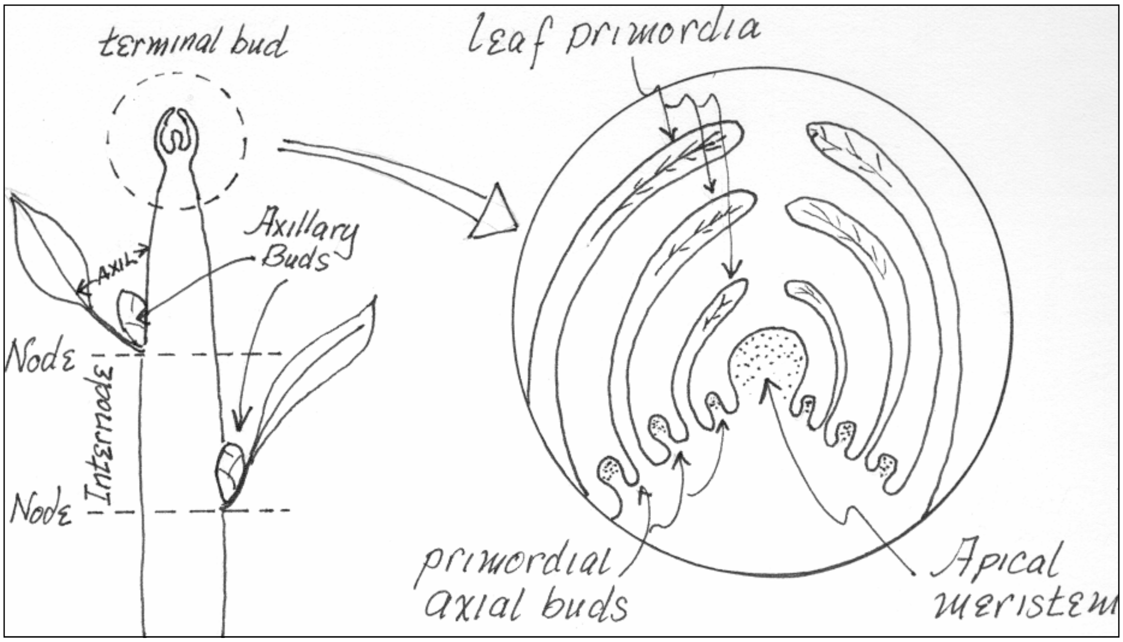
You'll notice that the new leafy twig, just emerged from the bud, has already formed a terminal, or end, bud. Other buds are also nestled between each leaf and the stem. These buds will fully develop at the end of the coming growing season, but their full development is put "on hold" during the during the Summer when the plant's energy is needed for growth, flower development, and reproduction.

So how does all this "stuff" — leaves, buds, stems, and even flowers — get into that tiny little bud? If you sliced the bud open to get a cross section, you would see little embryo bumps, arranged around an amorphous central area in the center. The little bumps, or primordial leaves and buds, will start to grow vigorously in the Spring, but to conserve space, they start off as nubbins which emerge from and grow outward from that central area which is called the **meristem**. The meristem is defined as a region of rapid cell growth and development.

Inside the bud, we find the beginnings of next year's twig. Note the primordial leaves and buds.



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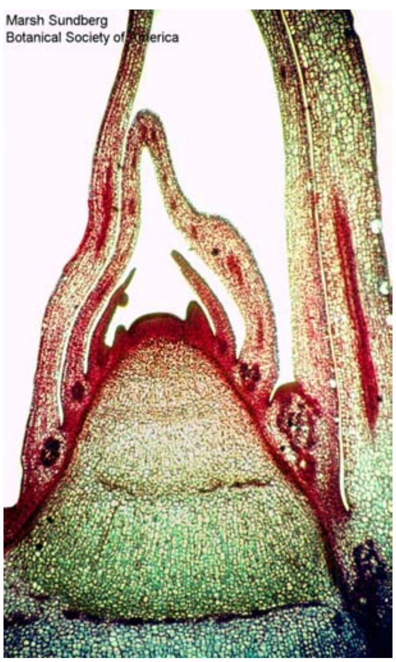
The central "nubbin" is the meristem, where the most rapid growth occurs. It is the beginning of a "conveyor belt". As each leaf or bud is formed, it moves down the proto-stem, and begins to grow and develop, getting larger and more complete as it moves "downstream". In the lengthwise section of the stem in the photomicrograph below, the developing leaves and buds appear to march down from the meristem in straight lines. This straight-line movement down the stem, however, does not occur in all plants, as we shall see.



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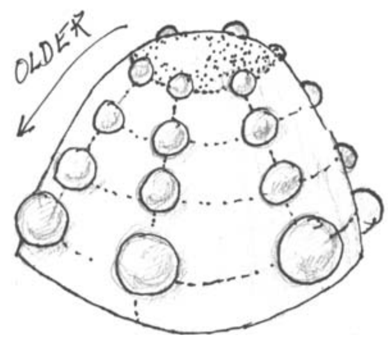
In this photomicrograph from the Botanical Society of America, we see an actual terminal bud, sliced lengthwise. Note the primordial buds and developing leaves, and how they both become larger and more developed as you move down from the tip of the stem.

Of course, the stem tip is a dome-shaped surface, and each leaf or bud primordium may be represented as a lump of specialized cells, which appears to move down from the top of the dome as the dome grows and elongates. The older the primordium, the larger and more fully developed it becomes. In the arrangement at the right, the primordia "move" straight down the side of the dome, along "meridians of longitude". The "latitude circles" are primordia of the same age of formation.



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Phyllotaxy: Arranging Leaves (and other things) on Stems

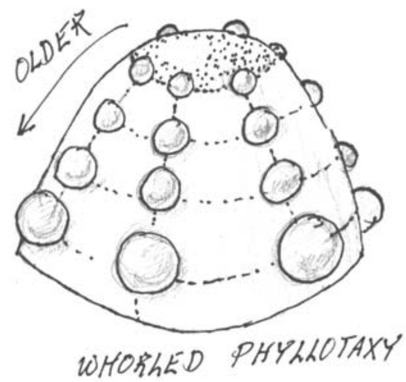
If we want to identify a wildflower or a tree or a shrub, the first place we go is usually an Audubon or Peterson Guide. The first thing the guides ask us to do is to decide how the leaves are arranged upon the stem. There are only three arrangements, thankfully, but the name given for this classification scheme, "phyllotaxy", is Greek to us. (It IS Greek: phyllos is Greek for "leaf", taxos simply means "arrangement".) We also have to know one other "buzzword": **node**. A node is simply an imaginary circle surrounding a stem where one or more leaves arise. If more than one leaf emerges from a node, the leaves are arranged symmetrically around the stem. Thus, a node is an imaginary circle surrounding a stem, just as a an imaginary circle of latitude girdles the earth. So let's look at the three arrangements. Find a leaf, trace it back to the stem. That's the node. Our phyllotaxy is based solely on what you find at that node.

1. Whorled phyllotaxy: More than two leaves arise at the same node. Usually you will find 5, 6, or 8 leaves at the same node. Broomstraw is a common weed with this characteristic.

007

Broomstraw node: 8 leaves arise from the same node.

In the bud, this plant forms leaves of the same age in "circles of latitude" around the dome of the emerging stem. The leaves on the same circle are said to be at the same node



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2. Opposite phyllotaxy: Two**,** and only two leaves arise at each node. This is a bit more common than the whorled phyllotaxy. You'll find it in many wildflowers, and in common trees such as Maple and Ash (the two twigs shown on Page 2).

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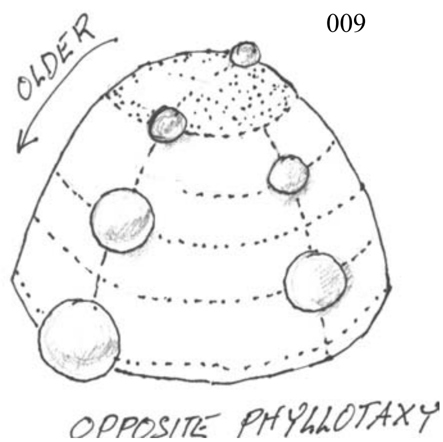
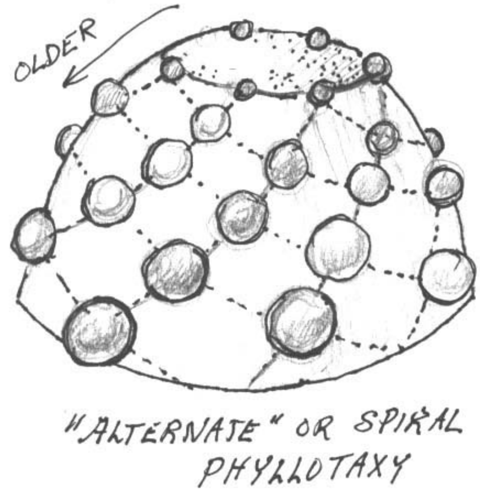


When this plant develops in the bud, the primordia are in pairs on each node, and each pair is exactly 90 degrees from the previous pair above it. In the drawing on the left of the Bouncing Bet, the lowest leaves are pointing North-South, and the higher pair of leaves are pointing East-West, and so on.

3. Alternate or Spiral phyllotaxy: Here we have one, and **only one** leaf arising on a node. Although this may seem simpler than having two leaves (opposite phyllotaxy) or many leaves (whorled phyllotaxy), this alternate arrangement gives rise to patterns of leaf development which are far more complex and interesting —not only that, over 80% of plant species follow this sort of leaf arrangement.

In general, a plant so arranges its leaves so that no leaf completely shades the leaf immediately below it. This ensures that each leaf gathers as much light as possible. If a leaf is pointing in exactly the same direction as another leaf immediately above, it can find its view of the Sun partially blocked unless it is much larger, or at a slightly different angle from the leaf above.



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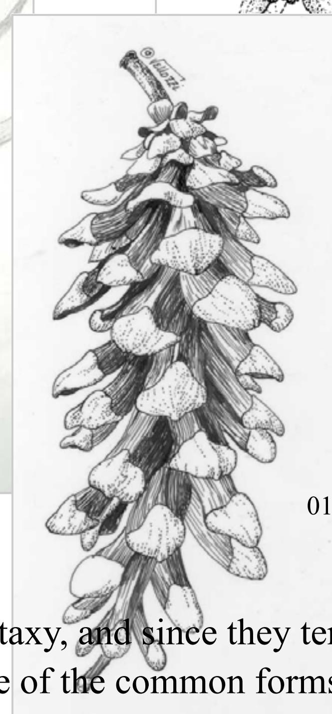
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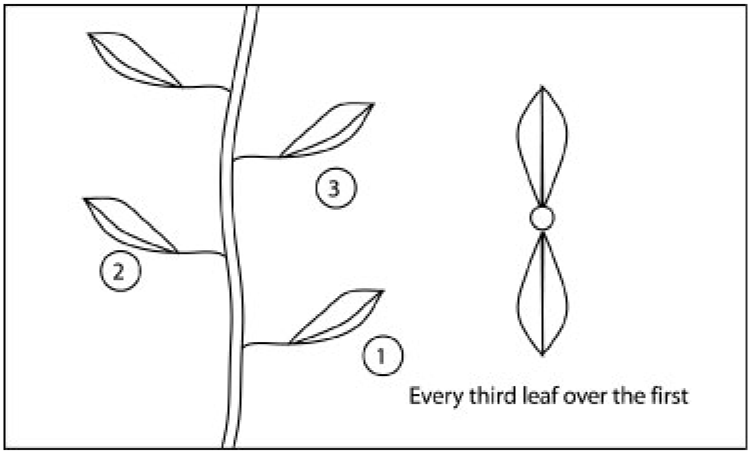
Since so many plants exhibit spiral phyllotaxy, and since they tend to be a challenge to draw, let's explore some more of the common forms of spirals...

Common forms of Spiral Phyllotaxy



016

Every third leaf over the first

Pick a leaf, call it Number 1, then go up the stem, counting leaves as you go. In order not to lose your place, you might want to tie a string to node #1, then wind the string up and around the stem until you come to a leaf that looks like it's in the same direction as the first.

Now, count the number of complete times you spiral around the stem.

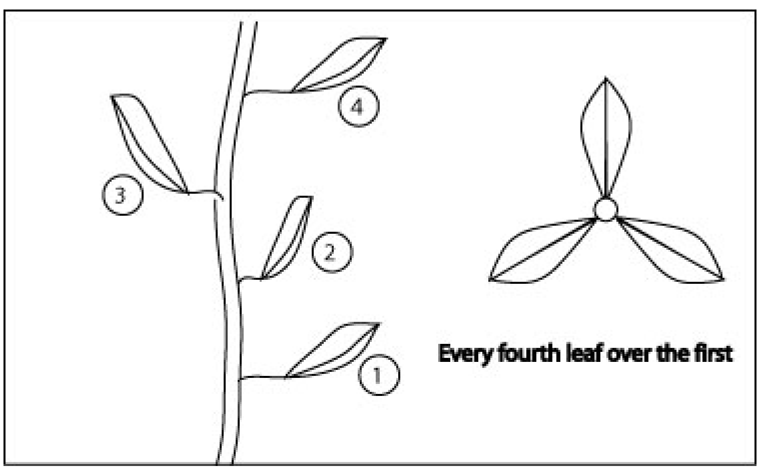
In this arrangement, every third leaf is in the same position as the first, and you go around the stem once. If you look straight down, you see two rows of leaves.

Let's express the leaf count and the number of turns as a fraction:

$$Spiral\ type\ = \frac{Number\ of\ complete\ turns\ around\ the\ stem}{Number\ of\ leaves\ touched\ , not\ including\ the\ first}$$

For the above spiral, we get **Spiral Type = 1/2**

If this formula seems a bit beside the point, it is often essential for botanists —and the rest of us who want to identify plants we find in the woods — in order to nail down the species correctly from our nature guides.



017

Every Fourth Leaf over the first

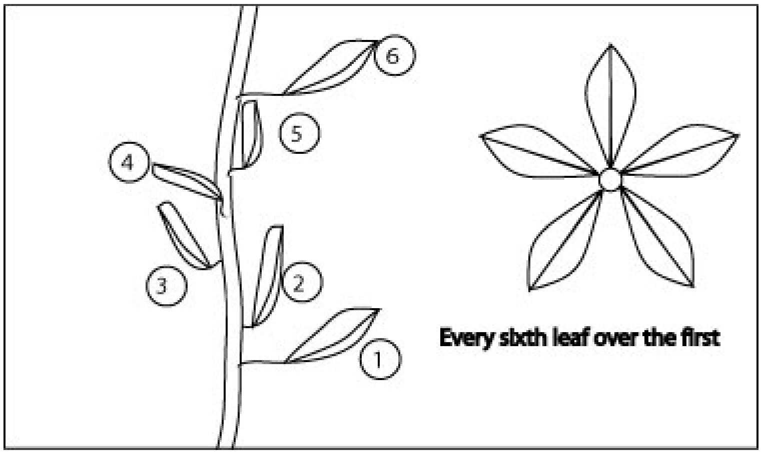
This arrangement is most obvious in Beech trees, and can be observed even in the Winter, since Beeches seem reluctant to shed their leaves! In this case, an aerial view shows three rows of leaves.

Node #4 is approximately at the same angle as node # 1, and we must wind around the stem once to get from #1 to # 4. Our observations are:

Number of complete turns = 1

Number of leaves touched, not including the first = 3

Spiral Type = 1/3



018

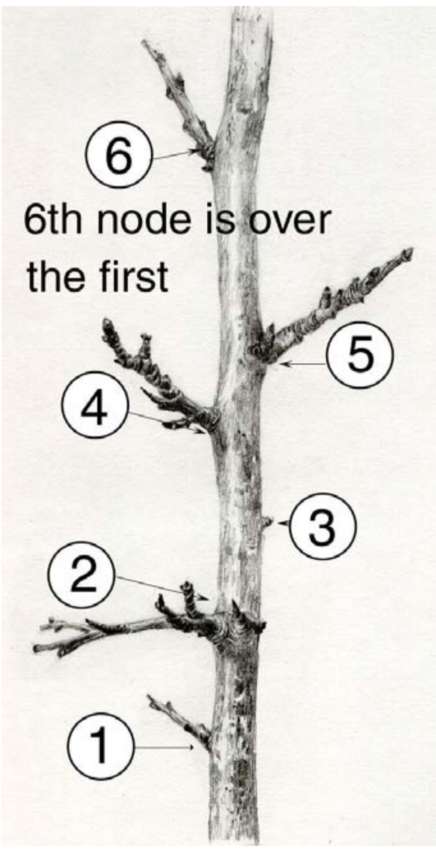
Every Sixth Leaf over the first

This is the most common of all, with the exception of the gymnosperms. It is found in Oaks, Cherries, Apples, and Poplars, for instance, as well as in many wildflowers. Our observations tell us:

Number of complete turns = 2

Number of leaves touched, not including the first = 5

Spiral Type =   2/5



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Sometimes, it's easier to see a spiral arrangement without the leaves. In the drawing on the left, this Winter version of a shrub allows us to substitute bare twigs for the leaves.

Fibonacci Series

So far, the three common forms of spiral phyllotaxy we have discussed have ratios that look like this:

$$\frac{1}{2} \quad \frac{1}{3} \quad \frac{2}{5}$$

But there are other forms of spiral phyllotaxy in other plants where every 9th node is over the first, every 14th, every 22nd, etc. The complete series looks like this:

$$\frac{1}{2} \quad \frac{1}{3} \quad \frac{2}{5} \quad \frac{3}{8} \quad \frac{5}{13} \quad \frac{8}{21} \quad \frac{13}{34} \quad \ldots$$

The higher fractions in this series are found in plants with greatly shortened stems, for instance in pine stems and cones.

Both the numerator and the denominator of these fractions are in the Fibonacci Series. For the numerators, the series is:

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89…

To create a Fibonacci Series, add any two successive terms. Their sum becomes the next term. For instance, for the first two terms, 1 and 1, their sum is 2, which is the next term in the series. Take 21 and 34. Their sum is 55, which is the next number in the sequence.

In any case, in our fractional notation, the numerator would be the number of times you must spiral around the stem to find a leaf in the same position as when you started.

The denominator will tell you how many rows of leaves you will see if you look at the stem head-on.

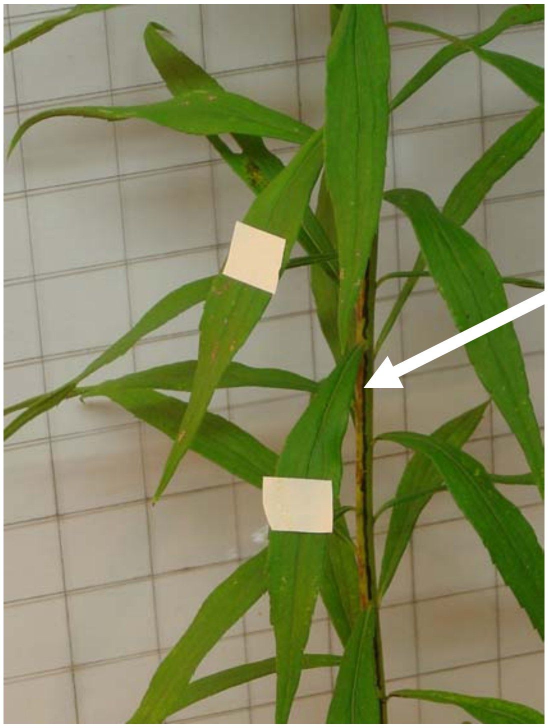
Crawling Up and Down Stems:

We decided to try the Spiral Phyllotaxy method, and actually pick a leaf on a complicated stem, then wind our way up the stem to a corresponding leaf, counting the number of times we must spiral around. Botany textbooks tell us that the most reliable way to obtain the Fibonacci sequence of our plant (as an invaluable way of determining its species) is to use a piece of string — and actually do it.

020

We picked a Goldenrod stalk, and checked to see whether it was indeed of the Alternate or Spiral persuasion. This is an easy test, since all you must do is make sure that there is only one leaf per node. We set the stem upright in the studio, holding its bottom in this case with a hobby alligator-clip grabber.

The setup is similar to the ones we use for drawing many plants. Eliminate distracting backgrounds with a piece of foam core board or mat board, and use some kind of a grid to get the general proportions. The grid shown happens to be transparent, made from a piece of clear acrylic. The acrylic was scored at one inch intervals and then inked with permanent black ink. This particular grid may be used either in front or in back of a specimen. We keep a variety of grids, transparent and opaque, for this purpose.



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Starting near the bottom, we pick a likely leaf, and mark it with a square of masking tape. The next task is to find a leaf above it which is approximately in the same direction. Sometimes this is a little hard to do, because plant stems tend to twist and turn in order to adjust themselves to local growing conditions. You can usually find a lengthwise ridge or groove in non-woody plants which will mark the correct leaf orientation. We highlighted the ridge in this case with a black felt-tip marker, which leads us to the next leaf in the same orientation.

022

Eventually, we have all the corresponding leaves marked with squares of masking tape. Each leaf is in the same orientation...or is it? These leaves are **approximately** in the same orientation, but each is slightly displaced from the one which is supposedly directly above it. This is true of most plants, which so arrange their leaves so that they do not shade each other. After all, the enormous energy needed to grow and maintain a leaf would be wasted if it were doomed to a life in the shade!

We observe that the “almost equivalent” leaves, one above the other, are forming along a spiral rather than in a straight line from the top to the bottom of the plant.

023

Our next step is to count the number of times we must wind around the stem in order to get to the next leaf above a marked leaf. We used white twine and long quilting pins to affix the twine to the stem, and placed pink flags at the stem location of each tagged leaf.

According to our measurements, we come up with the following result for our Fibonacci analysis using the Spiral Type Fraction:

Numerator: the number of complete turns around the stem: **3**

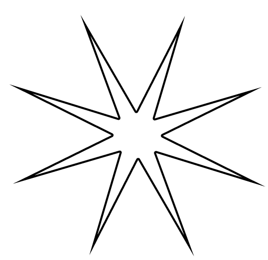
Denominator: number of leaves touched, not including the first: **8**

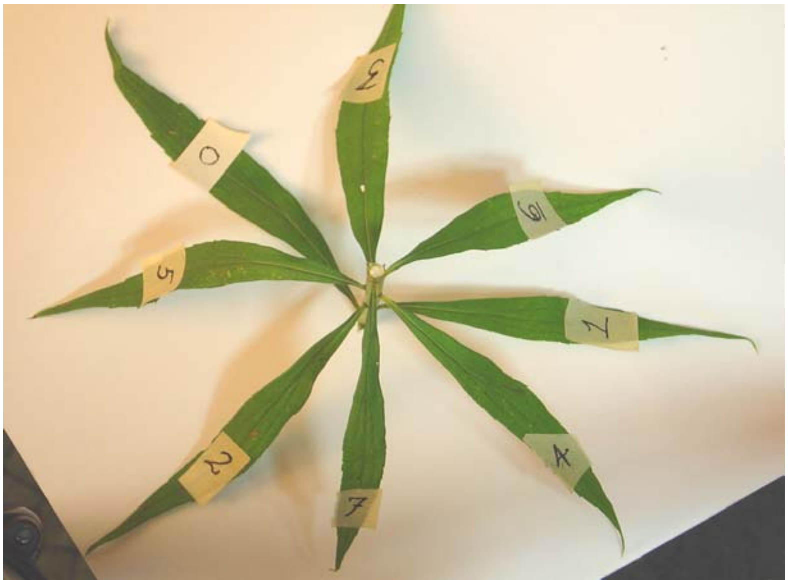
So our Spiral Type is $\frac{3}{8}$

This fits in nicely with the Fibonacci Sequence:

$$\frac{1}{2} \quad \frac{1}{3} \quad \frac{2}{5} \quad \frac{3}{8} \quad \frac{5}{13} \quad \frac{8}{21} \quad \frac{13}{34} \quad \ldots$$

We are interested to find out what we'll see if we look straight down the stem. Our guidelines suggest that the denominator of the fraction should tell us how many rows of leaves we should see, and we anticipate a star pattern with 8 rows, something like this:





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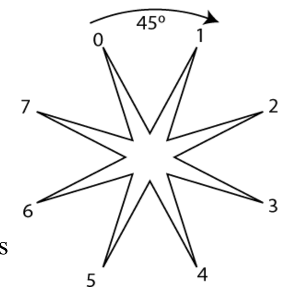
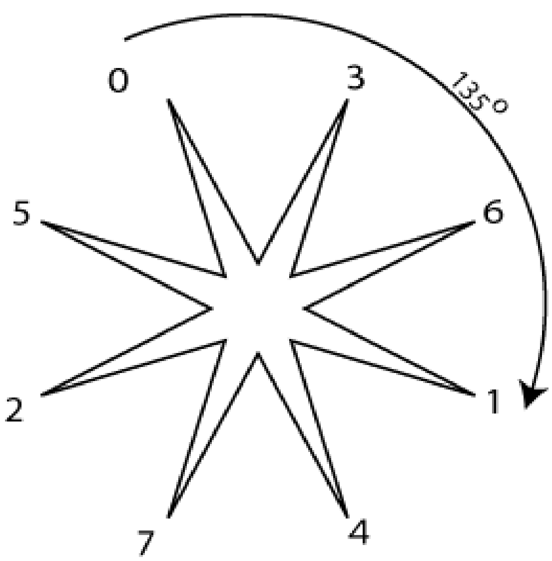
And sure enough, we see eight rows of leaves when we look straight down the Goldenrod stem. In the photo on the left, we have isolated and sliced off a complete set of 8 leaves from the stem. We have also labeled and numbered them with squares of tape, starting with 0, the lowest leaf in this segment. The next upward leaf is labeled 1, the next higher after that 2, and so on up to leaf 7. Leaf 8, which is not included on the stem segment, would have been approximately above leaf 0.



If we treated this segment of the stem as spokes of a wheel, we would expect the order of the leaves to be something like this, with the numbers of the leaves appearing as numerals on a clock, one following the other in clockwise sequence. We would only have to travel 45 ^{o} to get from one leaf to the next.

But the photograph clearly shows that leaf 1, following leaf 0, is 'way on the other side of the stem. In order to get from leaf 0 to leaf 1, we skip over two other leaf positions, and travel 135 degrees. Then to get from leaf 1 to leaf 2, we must again skip over two positions (occupied by leaves 4 and 7) and go through 135 ^{o} rather than 45^{o}. Schematically, the photograph looks like this:



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In short, the sequence of leaves, reflecting growth patterns as observed in the bud, is built up in a sequence that looks like this:

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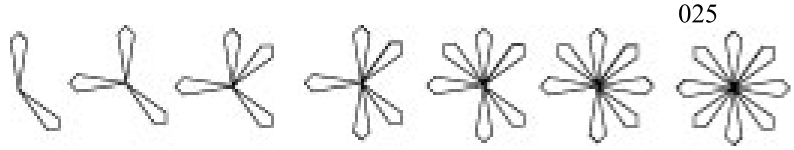
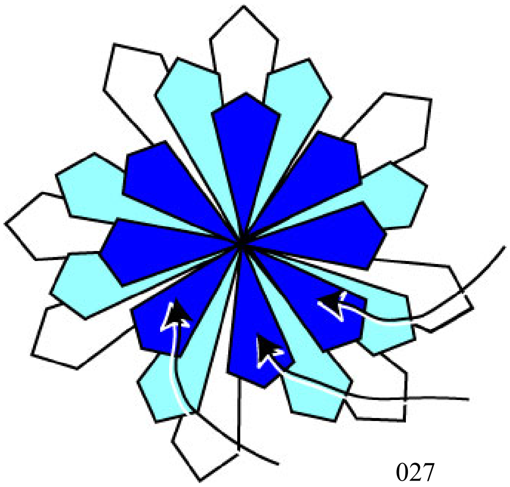


If this 135-degree spacing between successive leaves were strictly true, then the leaves, as seen from above, would consist of 8 rows, each of which would shade the corresponding leaf below it. As it is, it's approximately true, but how to explain the slight displacement between equivalent leaves in these vertical rows, which look so much like a spiral in the photographs?

As it turns out, the angle is closest to 137.5 degrees. Mathematicians would agree with our empirical observations. It appears, that in the world of plants, that's a magic angle.



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If we assume that the angle is closer to 137.5 degrees than the expected 135, then an expected plan view would still show the 8 distinct rows of leaves, but each is displaced from its equivalent below by a slight angle. Instead of the rows forming a straight line, we see the spiral begin to form.

The Aster, the plant we first met on page 1, had a leaf arrangement as follows: we found that every 6th leaf was above the first, and that it took us two revolutions around the stem to reach that 6th leaf. The numerator for our Fibonacci Spiral is then 2, and the denominator (number of leaves encountered not counting the first) is 5.

The fraction, 2/5 , predicts that we should observe 5 rows of leaves, if we look straight down the stem. Our sketchbook rendition of the Aster seen head-on confirms this prediction. There are five rows of leaves, but they are slightly displaced, forming a sort of spiral, rather than a straight lines parallel to the stem.

028

Our Aster's leaf deployment is not quite as neat a spiral as predicted by the theory, but then plants (like the rest of us!) do tend toward the ideal in spite of having to adjust to our local conditions. Leaves are really the plant's "solar panels" and their efficient deployment assures the plant an adequate supply of food.

Baby Phyllotaxies

The spiral arrangements of leaves may be observed, as we have seen, inside the buds formed at the end of the growing season. On the right is a photograph from the Smith College exhibit "Phyllotaxy", which shows an electron microscope view of a Norway Spruce bud. The leaf primordia form at the top of the dome-shaped meristem, then appear to march downward and outward as the stem elongates and enlarges, the proto-leaves getting larger as they develop as well. They're marching downward in spiral formation, but notice that we seem to see not one, but **two** spirals: one set going clockwise, the other counter-clockwise.

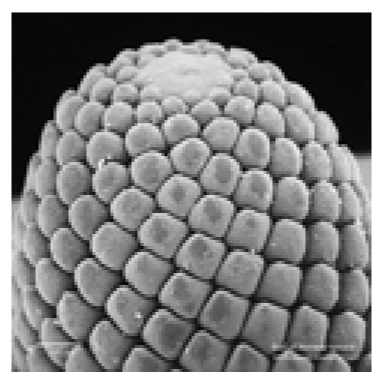

Photo credit: R. Rutishauser, University of Zurich. © 2002 Botanic Garden, Smith College. This and other photographs from the exhibit "Phyllotaxy" may be found at http://www.smith.edu/garden/exhibits/past-exhibitions.html

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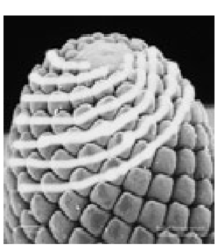

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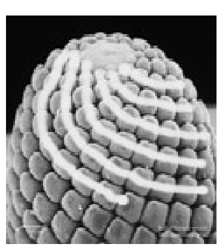

031

Para...what?

032

When we examined the Goldenrod and the Aster, we noticed the distinct spiral arrangement of the rows of leaves. For some plants, notably those with LOTS of leaves on a stem — such as the Norway Spruce we have just seen, or any conifer stem for that matter — the spiral nature of the arrangements of leaves is compressed, and more easily seen. We notice the spirals at once, and also see a second spiral which seems to cross the first. Take a mature Norway Spruce cone, for instance. (Note that we have propped it up against a grid, ready for drawing.) The Spruce cone scales, by the way, are modified leaves. We may observe the same sort of arrangement of needles on a Spruce stem, but the cone's arrangement is much easier to see.

033

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<u>Parastichies</u> is a term always encountered in spiral phyllotaxy.

The term is Greek (naturally) and comes from "stichos", which simply means " row". "Para" means "parallel", or "almost parallel". Specifically, it refers to the **two sets of spirals, clockwise and counter-clockwise**, which are observed in all alternate Phyllotaxies. The alternate arrangement is found in more than 80% of plants, so that knowing it is there, in some form or other, will make our first drawing of these plants easier. It's like the portrait artist's concept of the "skull beneath the skin" which enables him to understand quickly the framework of his subject.

To convince ourselves that this spiral business is true, we took another Spruce cone, and numbered the clockwise spirals, and painted the edge of the counterclockwise spirals. Our efforts looked like the photograph on the left. When the cone was observed head-on, we were better able to count the number of clockwise and counter-clockwise spirals.

036

037

We find there are 5 counter-clockwise spirals... ...and 8 clockwise spirals.

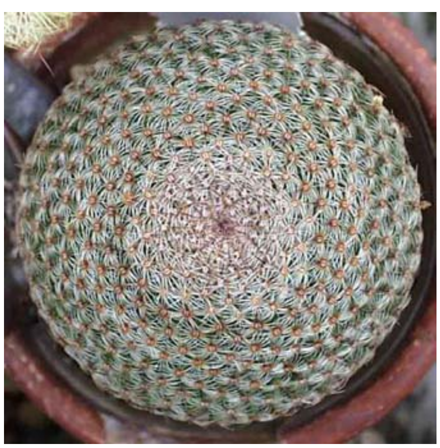
The **parastichy pair** for this cone is described as 5,8. That is, of the two sets of spirals, you have five going in one direction, and 8 going in the other.

It turns out that many plants exhibit parastichy pairs such as this, and they are always successive terms in the Fibonacci Series:

1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233...

Spruce cone

The Parastichies of higher pairs of Fibonacci numbers are also quite common, especially in flowers. Here are two examples from the Smith College "Phyllotaxy" exhibit:



Parastichy pair: 13, 21
©Smith College

038

Parastichy pair: 21, 34
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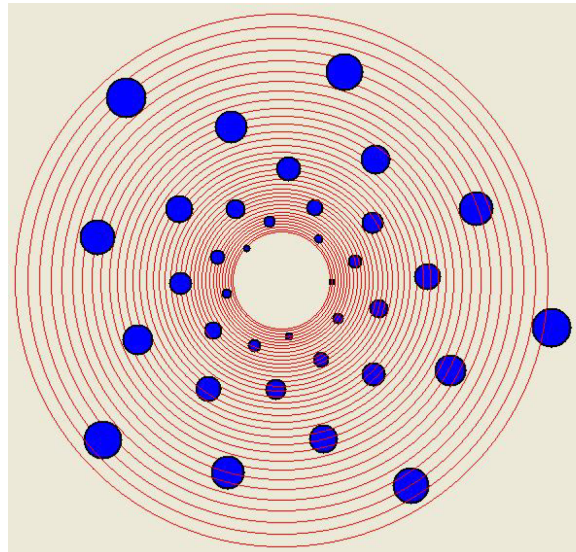
039

Modeling Leaf Growth and Development:

It has been demonstrated that when leaf primordia form at the edge of the meristem, they jostle for position so that the primordium finds itself in the least crowded spot in this region of rapid cell division and growth. They fit into a position where there is the least amount of crowding from previously-formed primordia. It turns out that the most favored spot for a new leaf is along a spiral, 137.5 degrees away from the one that formed before it, and slightly down the stem from the level where its predecessor formed. To convince ourselves that this is so, we wrote a VB.NET program to draw a picture of what this developing stem and its enlarging leaf primordia looked like. The concentric circles represent newer-to-older growth layers, starting from the meristem in the middle. The dots represent primordia, which get larger as they develop and move down the stem. Illustrated here is a growth spiral of the parastichy pair (5,8)



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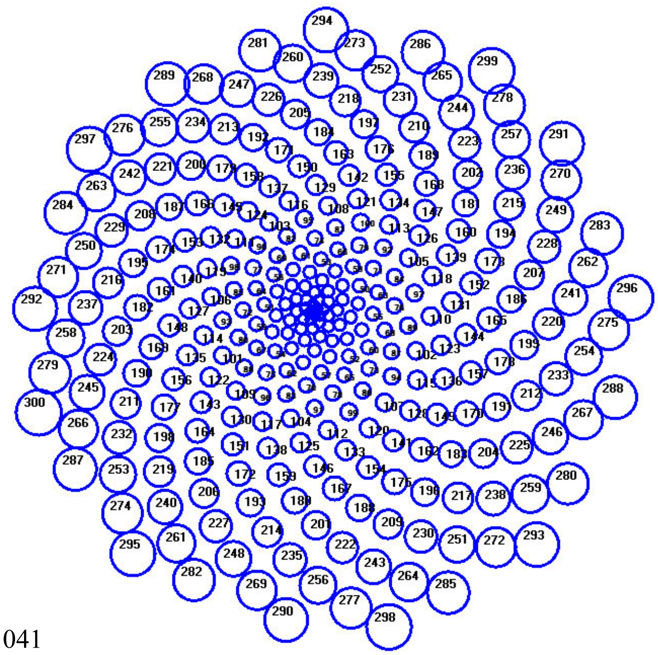

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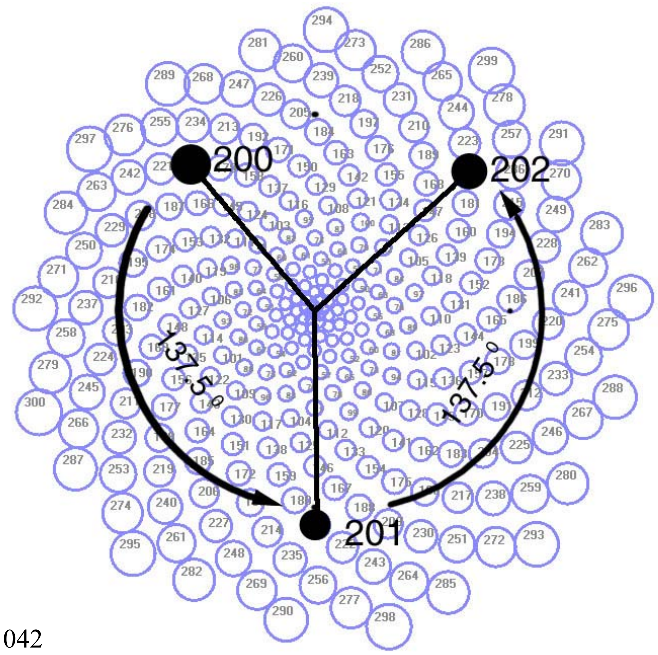

042

Our computer program obliges us if we want to see the order in which the primordia form by numbering them. We selected an option for a (13,21) pair of Parastichies (similar to a Daisy or Sunflower head) and asked it to number the primordia as they are formed. We picked number 200 and searched the "flower head" to see where number 201 would appear. As expected, it's 137.5 degrees away. And number 202 is similarly found.

Now what? …

Although we have hardly scratched the surface of spiral structures in plants, we think that even a nodding acquaintance with how plants develop and grow is of immediate use to anyone who sets himself the task of drawing plants realistically. The basis of any good realistic painting is a good drawing, and knowing and recognizing plant structures will help you navigate the "landmarks" of typical plants.

If you wish to explore the subject of mathematical plants further, here are a few of our favorite references for phyllotaxy:

1. **The "Phyllotaxy" exhibit at Smith College Gardens**. Although the exhibit is long gone, the web site remains, and we guarantee many happy hours "attending" this exhibit on the Web. (No sore feet, either!). Go to the site

http://www.smith.edu/garden/exhibits/past-exhibitions.html

And look for the "**Plant spirals: beauty you can count on**". Note: some of the plant photographs in this handout were from this on-line exhibit.

2. To look at the subject more closely, try the book **Phyllotaxis: A Systematic Study in Plant Morphogenesis** by Roger V. Jean. Cambridge University Press. ISBN: 0-521-40482-7

For some general references, we swear by the following:

3. **How to Draw Plants: The Techniques of Botanical Illustration** by Keith West. Watson-Guptill; ISBN: 0-8230-2356-7. This is by far the best book on practical plant illustration we've ever seen.

4. The Biology of Plants (6th edition) by Raven, Evert & Eichhorn (Thorough college introductory botany text) W. H. Freeman and Company; ISBN: 1-57259-041-6

5. The Guild Handbook of Scientific Illustration Editor: Hodges; Van Nostrand Reinhold; ISBN: 0-442-23681-Comprehensive guide for scientific illustrators in all fields, not just plants!

Classes covering specifically covering plant illustration may be found through the Internet, but we can (pardon us) vouch for one of them:

6. **Botanical Drawing at the Landis Arboretum**: A four-session workshop on the practicalities of drawing and painting plants. Currently scheduled for four Saturday sessions: July 8,15,22, and 29. For more information, contact the Landis Arboretum at http://www.landisarboretum.org, or contact the instructor directly at tv@keyserkill.com. Information may also be found at http://www.keyserkill.com Click on "Art Workshops".