Symmetry and Aesthetics in Contemporary Physics

CS-10, Spring 2016

Dr. Jatila van der Veen

Welcome!

Course Website:

http://web.physics.ucsb.edu/~jatila/symmetry-and-aesthetics-in-physics.html

How to reach me:

Email: jatila@physics.ucsb.edu

Office: 2225 Broida Hall x8418

Mobile: 805-403-7935

Course Expectations:

1. Attendance and participation in class
2. WEEKLY READINGS and Reading Reflections
3. 3 ART projects (explained in Reader)
4. Final Project: Physics Work of Art

This is a 4-point class.

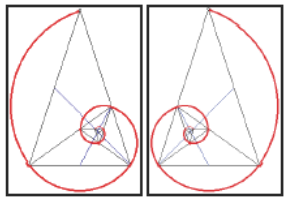
Required Readings:

Interdisciplinary Studies CCS 120, Section 2

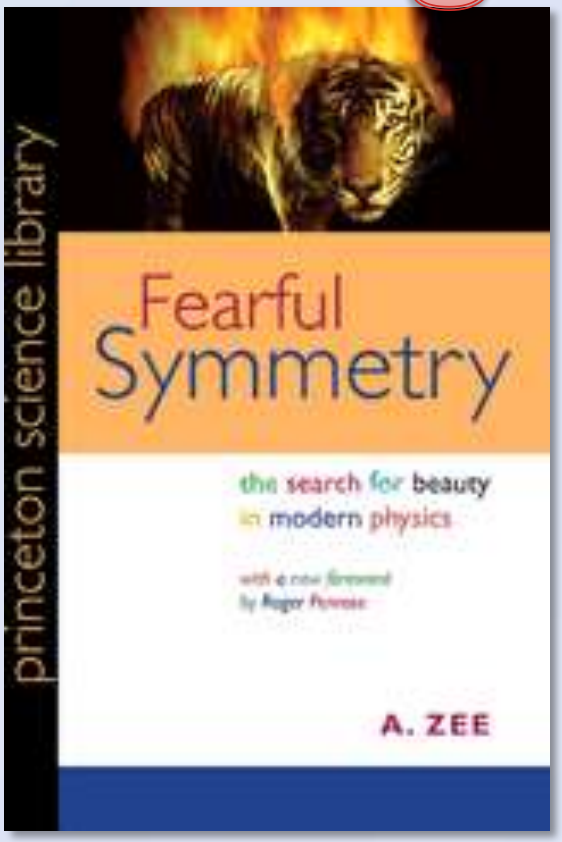
Symmetry and Aesthetics in Contemporary Physics

Instructor: Dr. Jatila van der Veen

Spring 2016



* ASSOCIATED STUDENTS *
* NOTETAKING AND PUBLICATIONS SERVICE *



Please bring to class with you.

Introductions:

Why are you taking this course?
What are you hoping to learn from it?

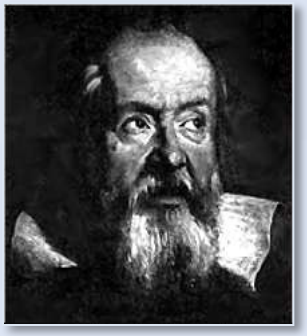
physics as a way of knowing

- **Ontology – the study of reality (existence, being)**
- **Epistemology – the study knowledge, how knowledge is acquired, and to what extent we can know something**

- ***What is reality?***
- ***What does it mean to say you "know" something?***

Reflect - Discuss with a partner - Share with the class

The Physics Party Line:



“ Philosophy is written in that great book which ever lies before our eyes – I mean the Universe – but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The book is written in the mathematical language … without which one wanders in vain through a dark labyrinth.” Galileo Galilei

“External physical reality is not only *described* by mathematics, it *is* mathematics.”

-Theoretical physicist, Professor Max Tegmark, MIT

WHAT DO YOU THINK?

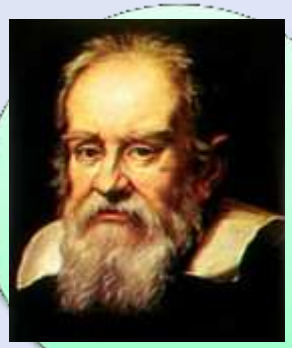
In physics we take this for granted, but…
Is the universe truly mathematical, or is it just our perspective?

Reflect - Discuss with a partner - Share with the class

A variety of opinions:

Math is Divine, pure, exists independently of humans, waiting to be discovered.

Math is the language of the cosmos, independent of humans, waiting to be discovered, embedded in Nature and embodied in the Laws of Physics.



Math and science clip the wings of imagination. To describe Nature mathematically destroys its beauty.

Math is purely a human invention; the laws of physics are expressed in math because that's how our brains are wired. Fittest theories survive.

The complexity of the universe is built from simple computer programs.

From Mario Livio's book The Golden Ratio

My opinion, and the underlying assumption of this course:

Math and Art are complimentary, interdependent ways of knowing and meaning-making.

Physicists discover mathematical relationships in nature.

Math is predictable and objective, and provides independent verification of physical observations and theories.

Thus math is a suitable language for describing the regularities in the phenomenological universe.

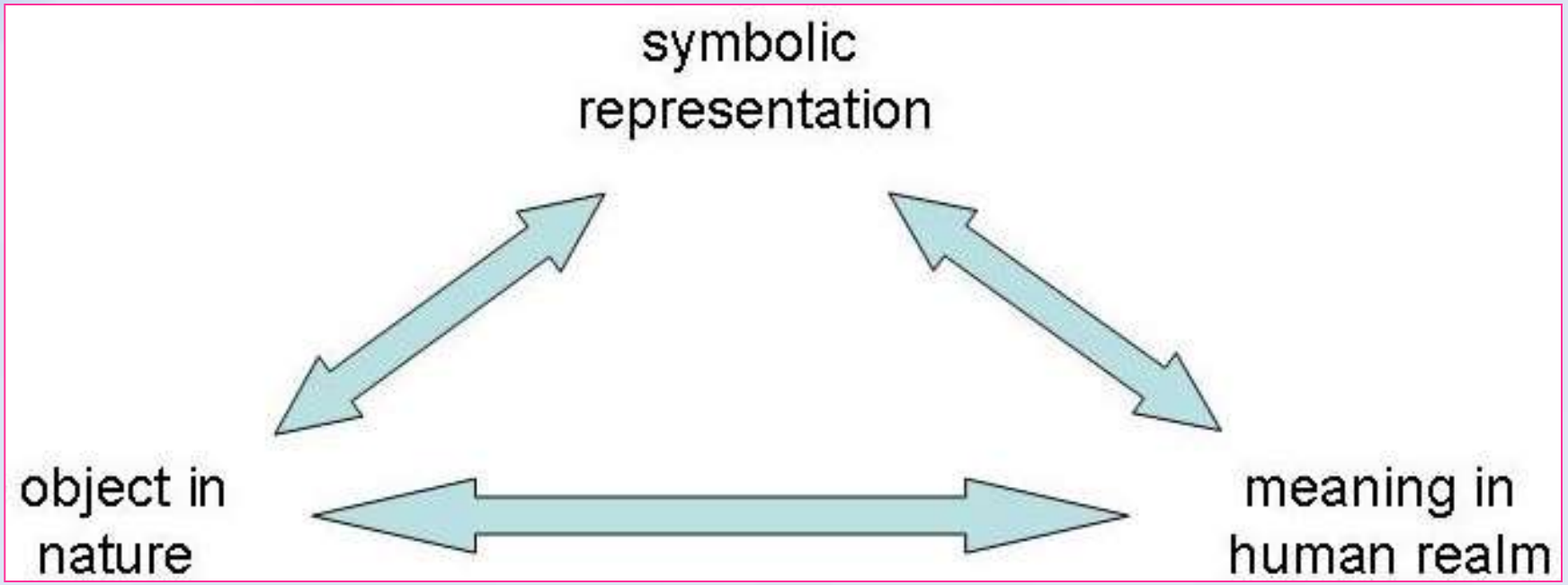
My opinion, and the underlying assumption of this course:

Math and Art are complimentary, interdependent ways of knowing and meaning-making.

Artists *interpret* the cosmos.

Art is subjective and individual, yet the public relies on art to visualize physical theories.

Thus the artist can play a seminal role in interpreting physical theories for society, giving symbolic meaning to mathematical concepts that can have profound influence on the way people think about physics.



All civilizations have symbol systems which grow out of their culture and inform their view of the cosmos.

For example…

0	1	2	3	4
5	6	7	8	9
10	11	12	13	14
15	16	17	18	19
20	21	22	23	24
25	26	27	28	29

<u>Mayan civilization</u>: counting in base 20; one of few ancient cultures to use the concept of zero, allowing them to count into the millions; Nature and cosmology were interwoven into the artwork and life of the Maya.

Indian mathematicians:

- **developed zero**
- **originated – and + numbers**
- **developed series expansions**
- **originated the "Arabic" numeric notation of 0 to 9**

Bashkara 1 (680-600 BC)

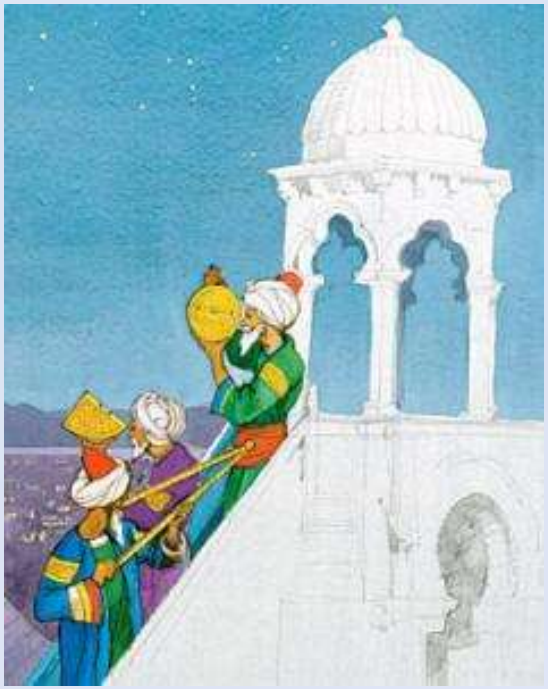
Brahmagupta (598–668 AD)

Madhava (1350-1425)

Islamic mathematicians (800's – 1400's) discovered:

- **Algebra;**
- **the17 ways to tile a plane – seen in the Alhambra;**
- **binomial theorem;**
- **astronomical observations that were the foundation of the discoveries of Copernicus, Kepler, and Galileo.**

Muhammad Al-Khwarizmi (c.780-850 AD)



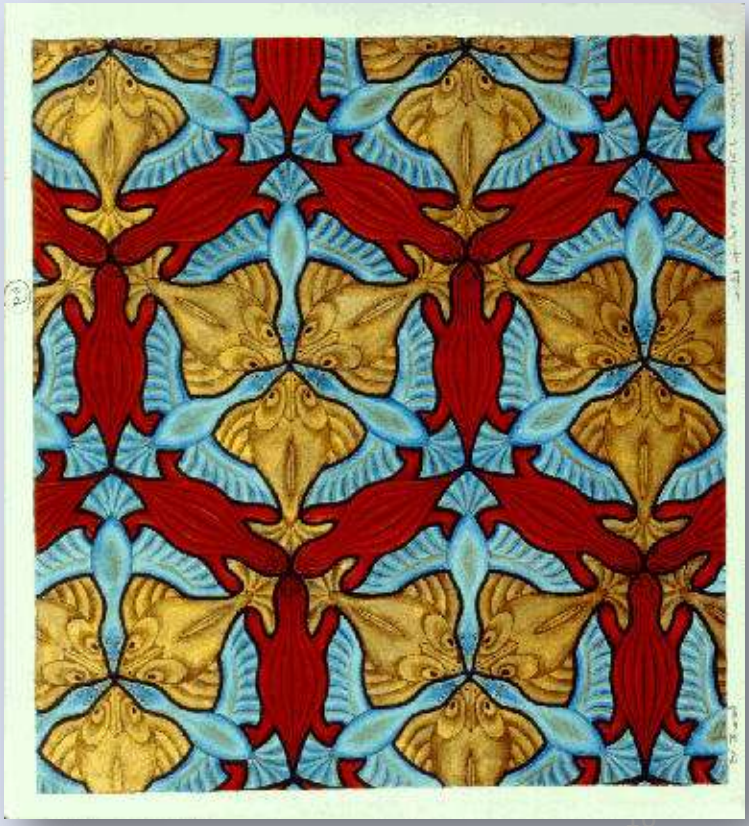
Muhammad Ibn al-Hasan Nasir al-Din al-Tusi, 1201 to 1274

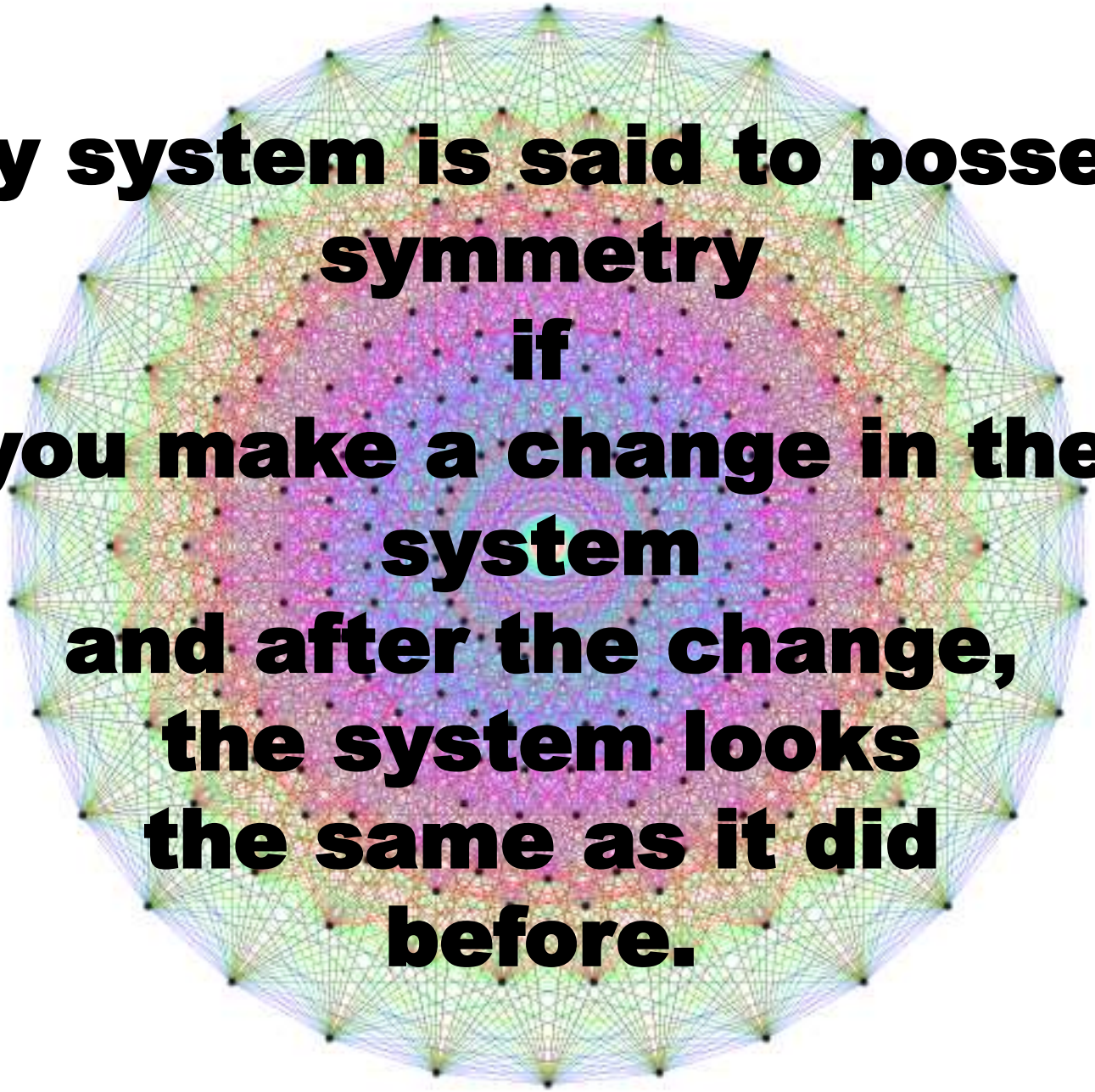
Symmetry and Aesthetics in *Contemporary Physics*

Aesthetics: The branch of philosophy dealing with the nature of beauty, art, and taste. (Wikipedia)

Symmetry: Dynamically defined: **Sameness within change**

Expressed as regularity of form, repetition in space and time, recognizability, interchangeability of parts, constant relationship of parts to whole.





Any system is said to possess symmetry if you make a change in the system and after the change, the system looks the same as it did before.

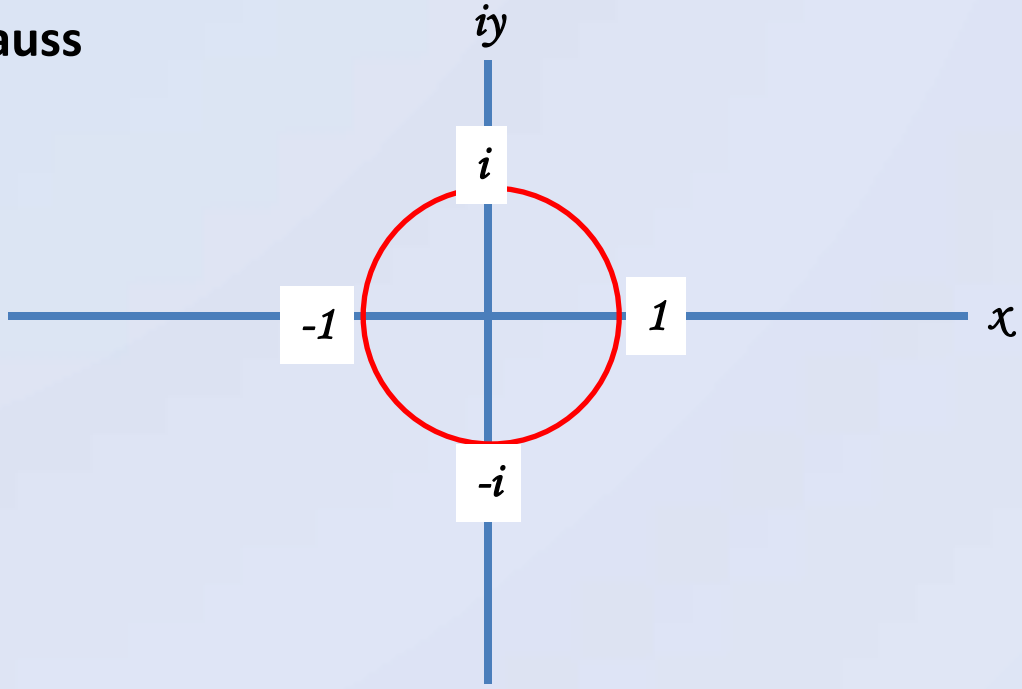
Symmetry in repeating patterns has been an important principle in the art of many cultures.

Symmetry was linked to solutions of equations by mathematicians of 18th century Europe.

Carl Friedrich Gauss
(1777-1855)

Gauss invented a new 'space' - the complex plane – to solve equations such as $z^4 = -1$ which turned out to be related to symmetries of regular polygons and have applications in Nature.

$$z = a + bi$$



$$i = \sqrt{-1}$$

$$i^2 = -1$$

$$i^3 = -i$$

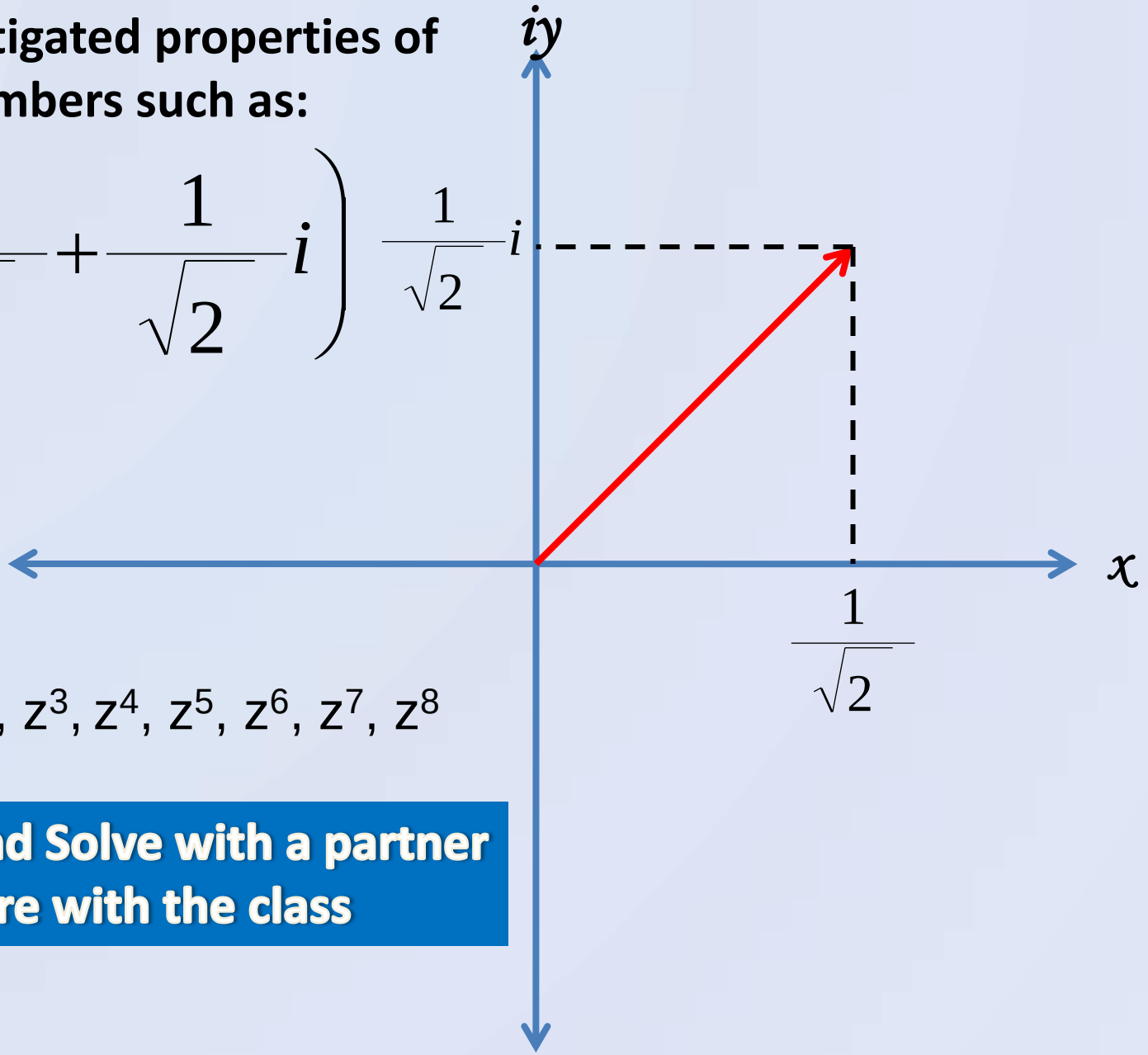
$$i^4 = 1$$

$$i^5 = i$$

$$i^6 = -1 = i^2$$

Gauss investigated properties of complex numbers such as:

$$z = \left(\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}} i \right)$$



Find $z^2, z^3, z^4, z^5, z^6, z^7, z^8$

Discuss and Solve with a partner
Share with the class

$$z = \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}i$$

$$z^2 = i$$

$$z^3 = -\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}}i$$

$$z^4 = -1$$

$$z^5 = -\frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}i$$

$$z^6 = -i$$

$$z^7 = \frac{1}{\sqrt{2}} - \frac{1}{\sqrt{2}}i$$

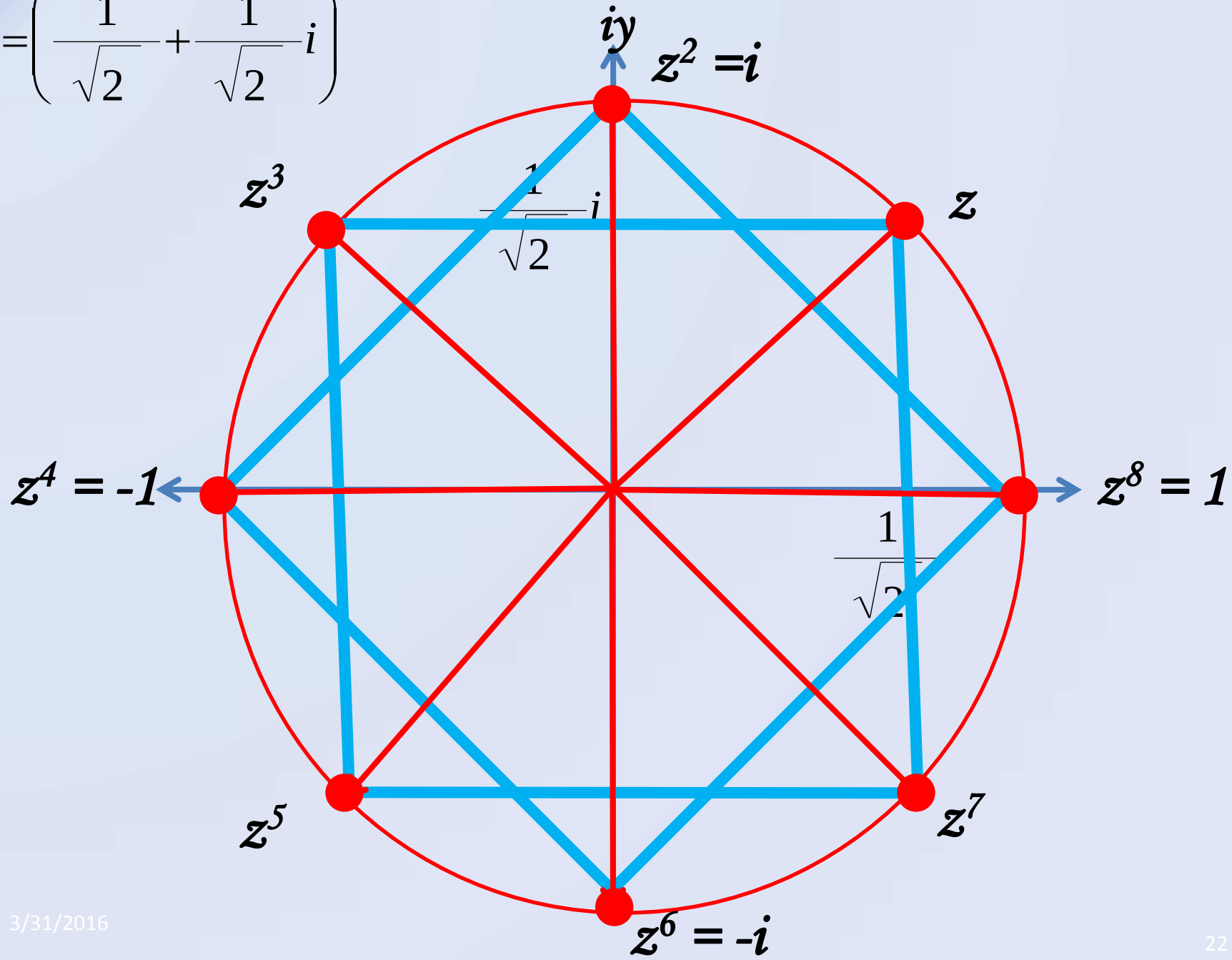
$$z^8 = 1$$

Now:
Plot the points on the complex plane.

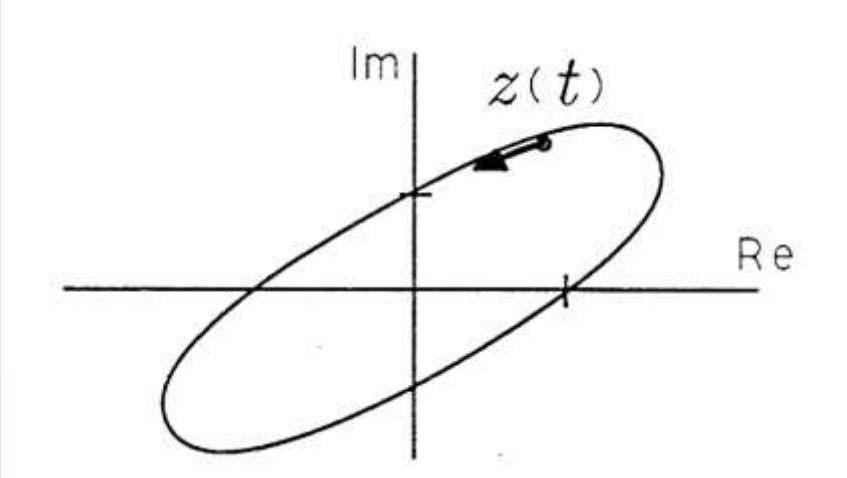
Connect the dots – what do you get?

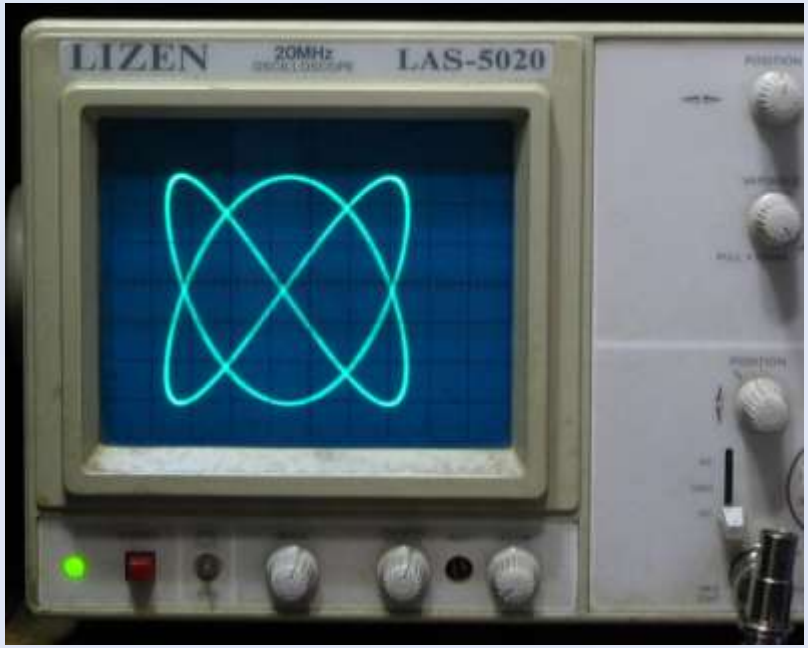
Continue working with same partner.

$$z=\left(\frac{1}{\sqrt{2}}+\frac{1}{\sqrt{2}}i\right)$$



Physical manifestations of complex numbers include anything to do with oscillations and waves, including circuits, music, light, seismic waves





https://www.youtube.com/watch?v=aUi8SnGGfG8

https://www.youtube.com/watch?v=c5Bcvvw1t4I

http://www.jerobeamfenderson.net/post/79266440786/nuclearnoise

A BRIEF TALE of a number which, once discovered, seemed to show up everywhere.

$$\frac{a+b}{a} = \frac{a}{b} = \varphi$$

Euclid of Alexandria
~ 325 BC - ~ 265 BC

Discovery attributed in the West to Euclid:
Any line segment can be divided such that the ratio of the larger portion to the smaller is equal to the ratio of the whole segment to the larger.

What is the value of φ ?

$$\frac{a+b}{a}=\frac{a}{b}=\varphi$$

Let: $a=1$

$$a+b=x$$

Then: $\frac{x}{1}=\frac{1}{x-1}$

Thus:

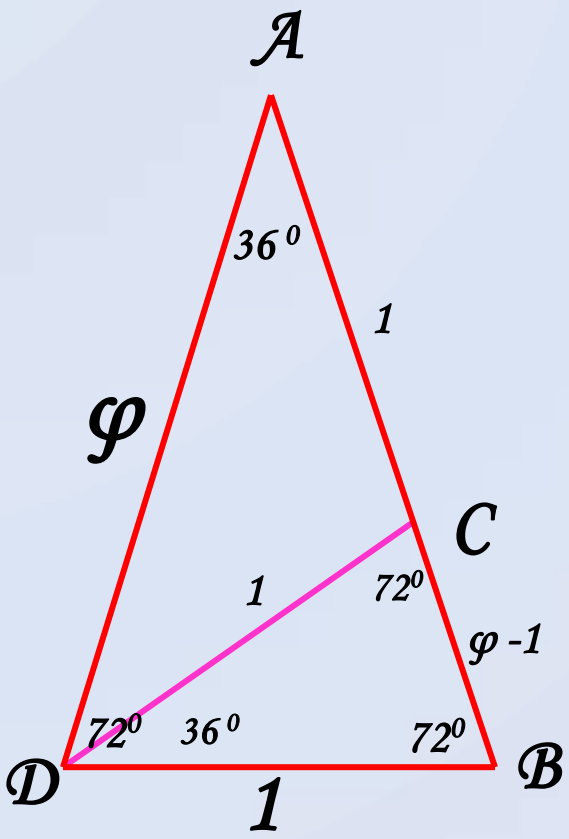
$$x^2-x=1$$

$$x^2-x-1=0$$

$$x=1\pm\frac{\sqrt{1-4}}{2}$$

$$x_1=1+\frac{\sqrt{5}}{2}=1.6182\ldots$$

$$x_2=1-\frac{\sqrt{5}}{2}=0.6182\ldots$$



$AD / DB = \varphi$

Euclid defined the Golden Rectangle

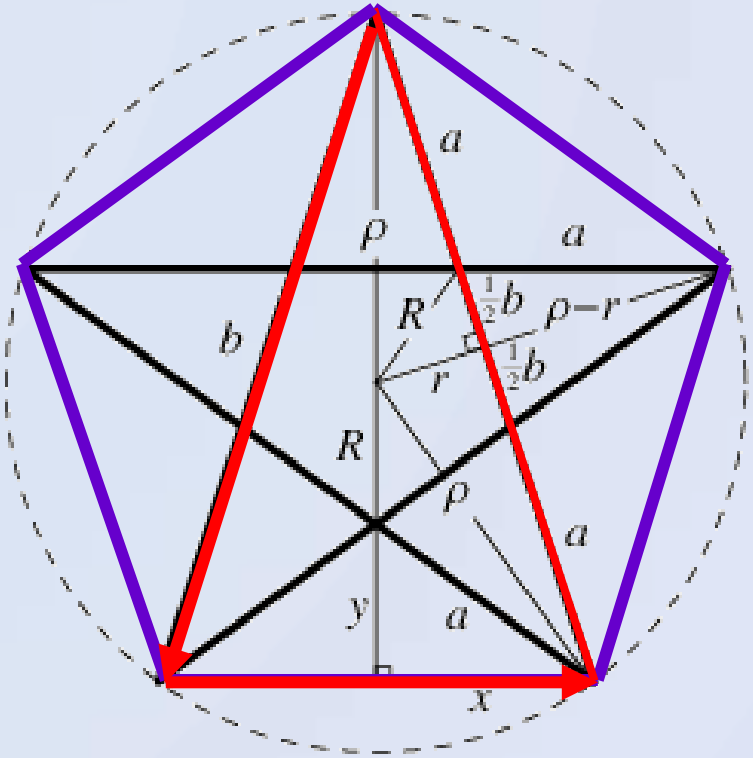
ratio of sides = φ

1

φ

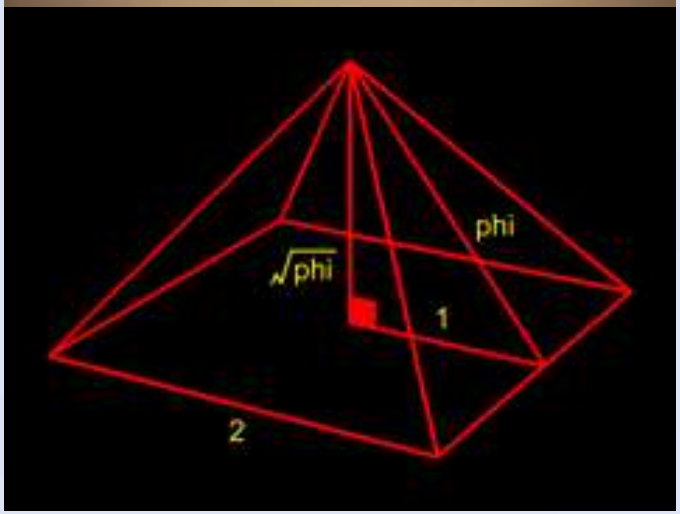
and the Golden Triangle:

ratio of legs to base = φ



Five Golden Triangles inscribed in a circle make a pentagram.

ONCE φ **was discovered as a solution to a math problem, popular fascination set in, and the notion of a perfect proportion was taken up by artists and architects…**

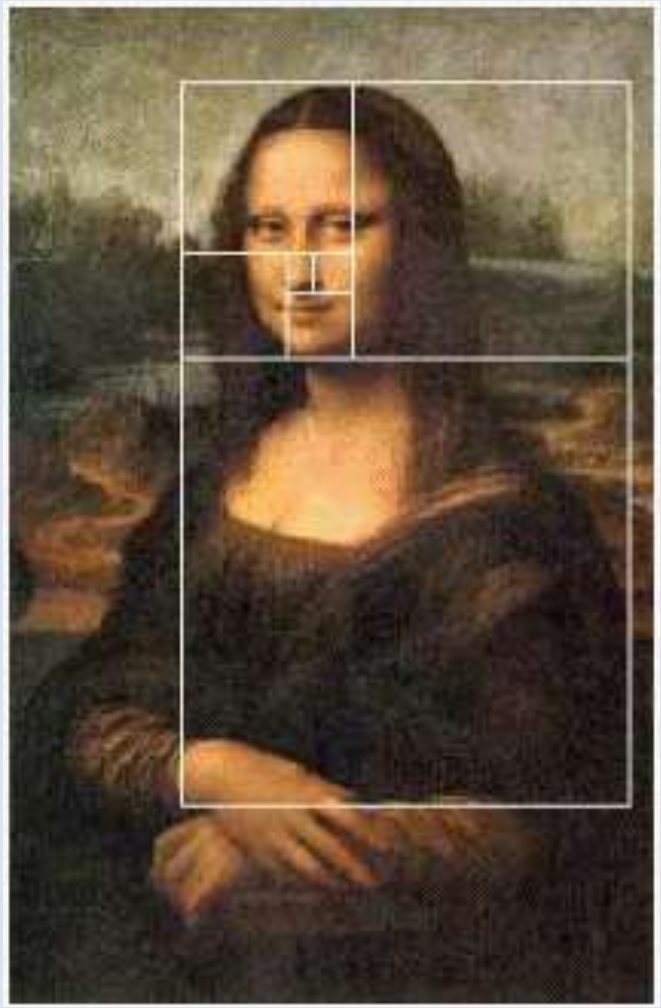


Great Pyramid at Giza

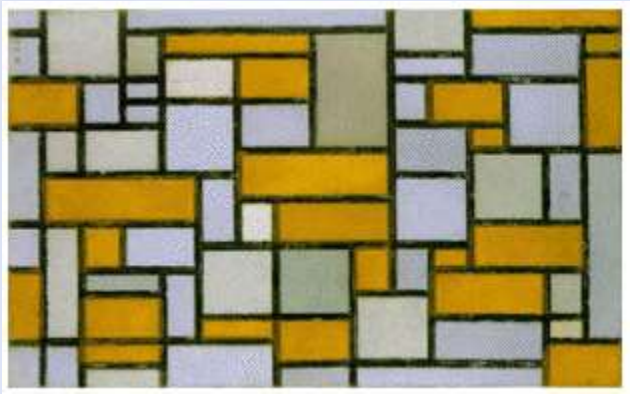
Michaelangelo

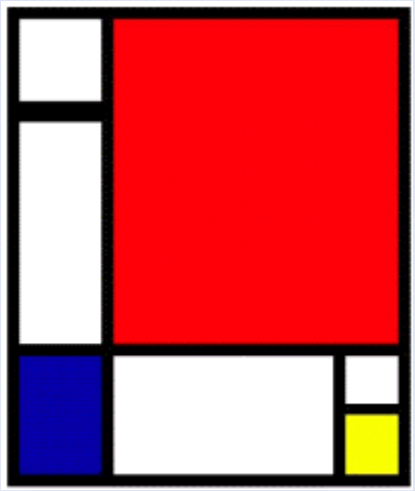
Raphael

Alhambra



Da Vinci





Modern art by Mondrian ~1926

…and was discovered lurking in a certain series that is manifest in rabbit and bee reproduction and seed growth in plants.

Leonardo Pisano
Filius Bonaccio
"Fibonacci "
(1170-1250)

Fibonacci Numbers

```
1+2 = 3
  2 + 3 = 5
    3 + 5 = 8
      5 + 8 = 13
        8 + 13 = 21
          13 + 21 = 34 ...
```

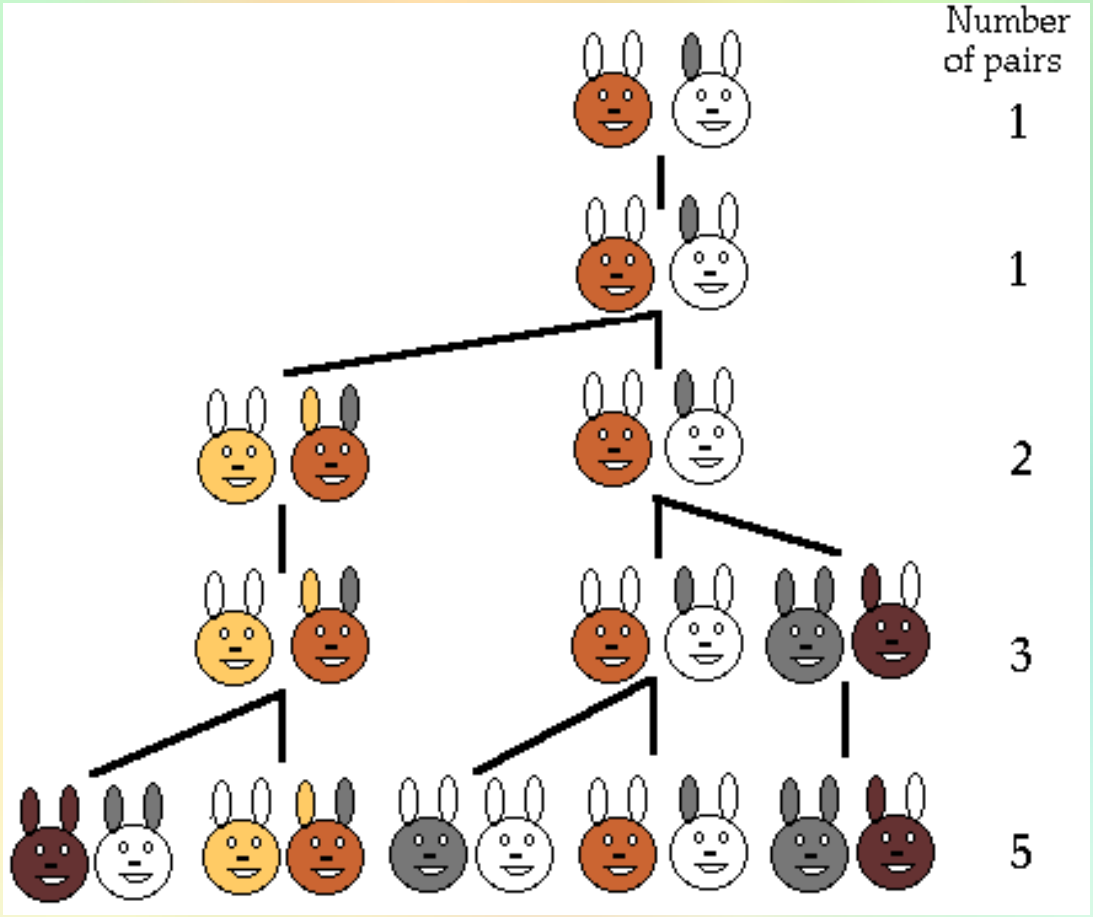
traveled extensively and studied Indian and Arabic mathematics

First in Europe to publish this sequence

Fibonacci's Rabbits: How fast can an ideal pair of rabbits reproduce?

Suppose a newly-born pair of rabbits, one male, one female, are put in a field. Rabbits are able to mate at the age of one month, and they have a one month gestation period. Thus, at the end of the second month a female can produce another pair of rabbits. Suppose that our rabbits never die and that the female always produces one new pair (one male, one female) every month from the second month on. How many pairs will there be in one year?

Think about this
Discuss with a partner
Share with the class



start with 1 pair of babies

after 1 month they mate

after 2 months 1st pair produces a pair

after 3 months 1st pair produces a pair but 2nd pair is too young

after 4 months 1st and 2nd pairs produce a pair each; 5 pairs

after 5 months.....8 pairs
after 6 months…13 pairs
after 7 months….21 pairs
after 8 months… 34 pairs
after 9 months….55 pairs
10……..89 pairs
11……144 pairs
12……233 pairs
= 466 rabbits

1 + 2 + 1 + 2 + 2 = 8

2 + 3 + 2 + 3 + 3 = 13

In each generation you have the number of pairs of rabbits from the previous generation, plus the number of pairs that were born to rabbits at least two months old.

cute picture from
http://www.maths.surrey.ac.uk/hosted-sites/R.Knott/Fibonacci/fibnat.html#Rabbits

The ancestry code of bees

If an egg is laid by a single female, it hatches a male. If, however, the egg is fertilized by a male, it hatches a female. Thus, a male bee will always have one parent – a female - while a female bee will have two – a male + female.

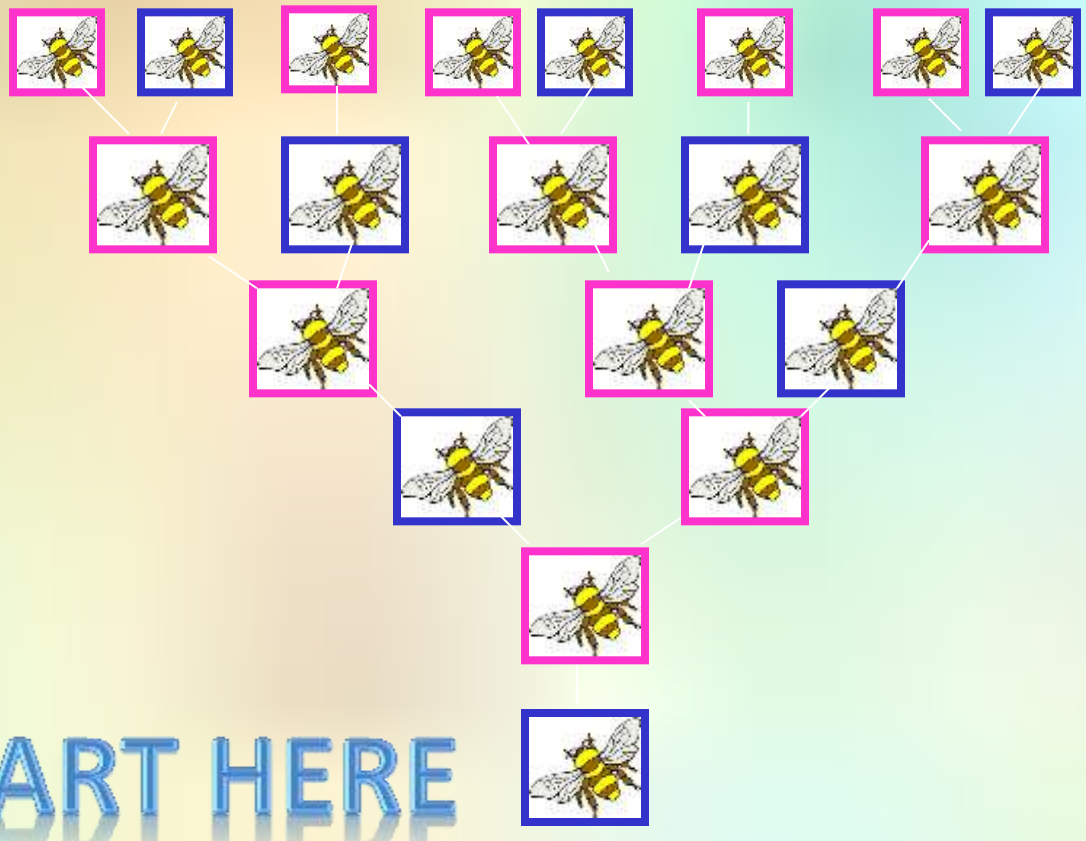
Suppose you have a single male bee. How many ancestors does he have if you go back 10 generations ?

Think about this
Discuss with a partner
Share with the class

ETC…

F M+F M+F F M+F F M+F M+F F M+F F M+F M+F

M+F F M+F M+F F M+F M+F F



START HERE

89

55

34

21

13

8

5

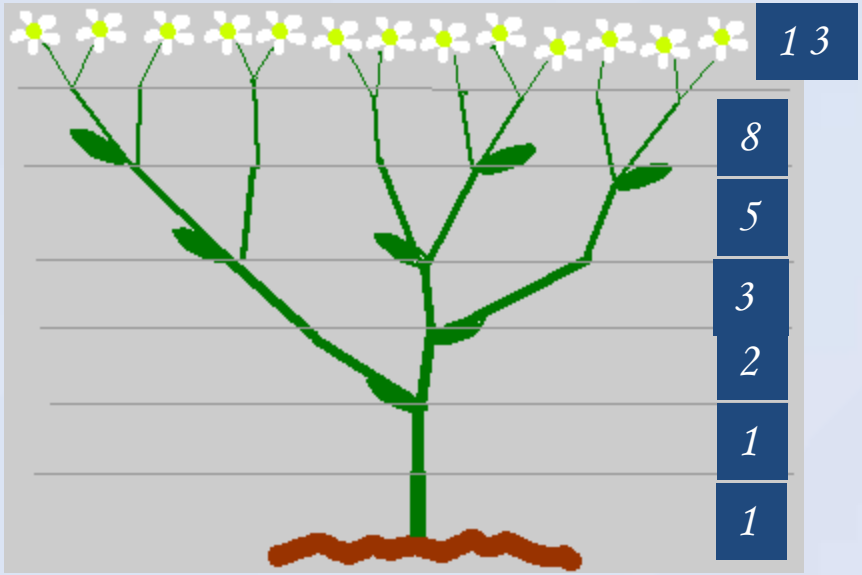
3 Bee's ggp's

2 Bee's gp's

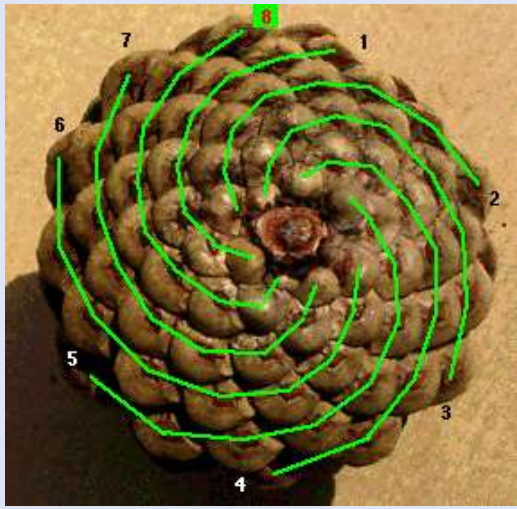
1 Bee's Mom

1 Our Bee

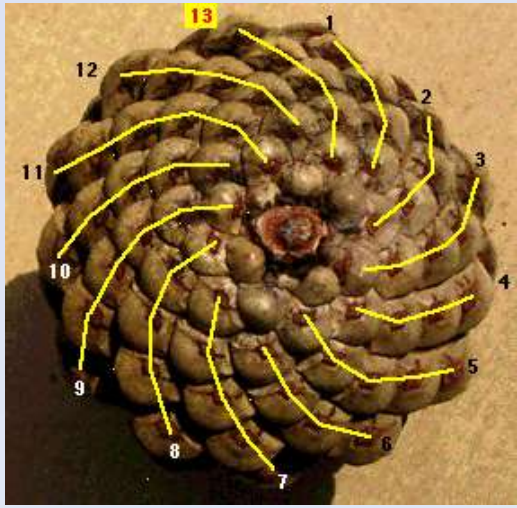
Flowers, seed heads of flowers, and pine combs display Fibonacci numbers in their numbers of petals and growing points, closest packing of seeds, and spirals of petals:



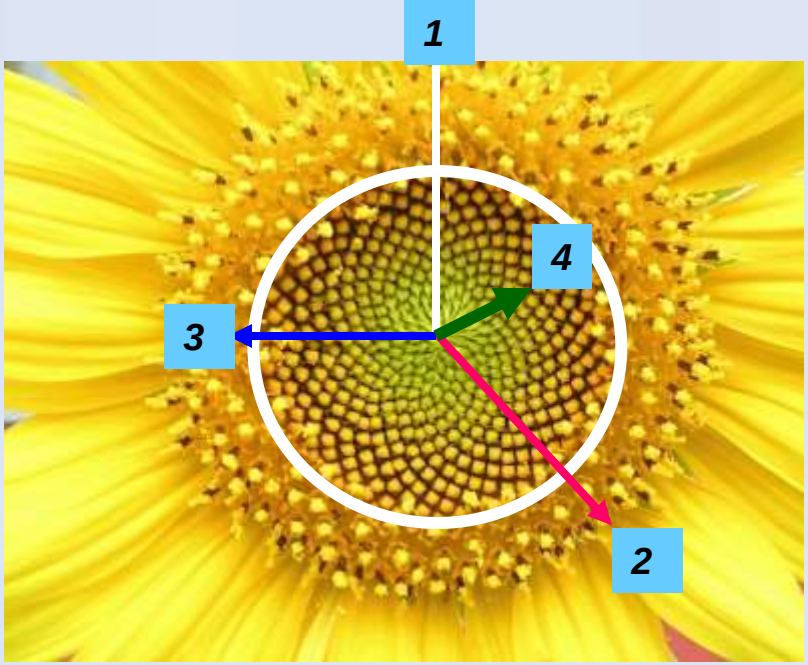
8 spirals going clockwise...



13 spirals going counter-clockwise



commonly, flower seed heads have 34 and 55 spirals, 55 and 89, or 89 and 144, for large sunflowers



Why should this be so?

As the plant grows, each new bud appears on a radial growth line which is 137.5^0 from the radial growth line of the previous bud. In this way, buds fill the spaces efficiently, without undue competition for space, light, water, food.

Experiments simulating seed growth have shown that this growth pattern very likely represents a stable state of minimal energy for a system of mutually-repelling particles, in this case iron particles in a magnetic field simulating seeds or buds.

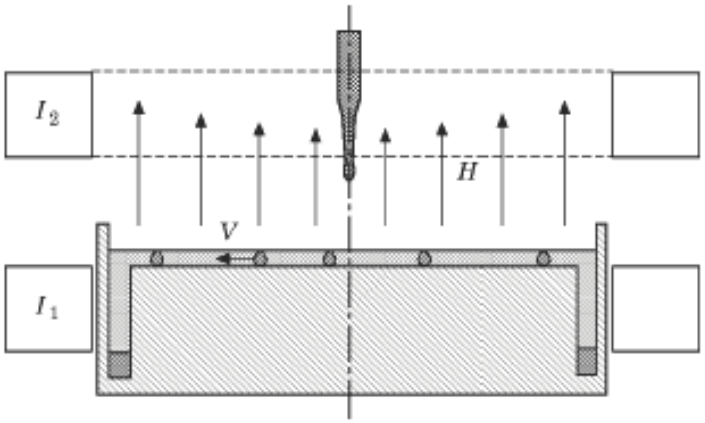
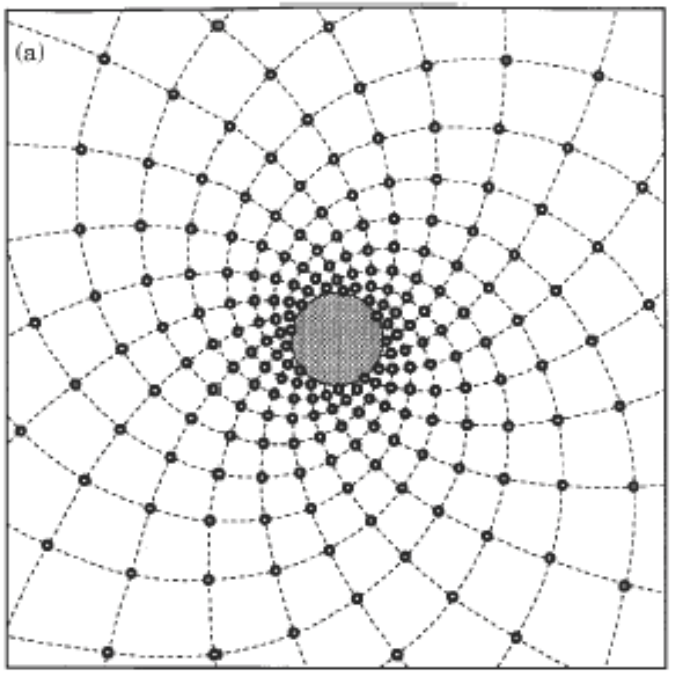
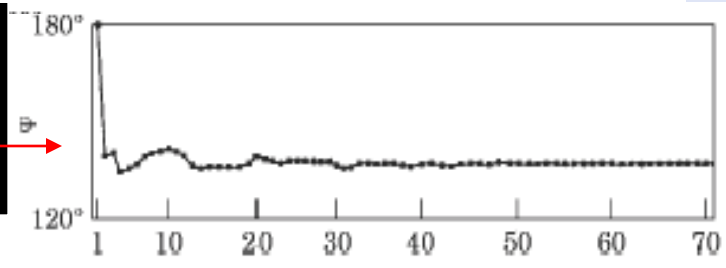
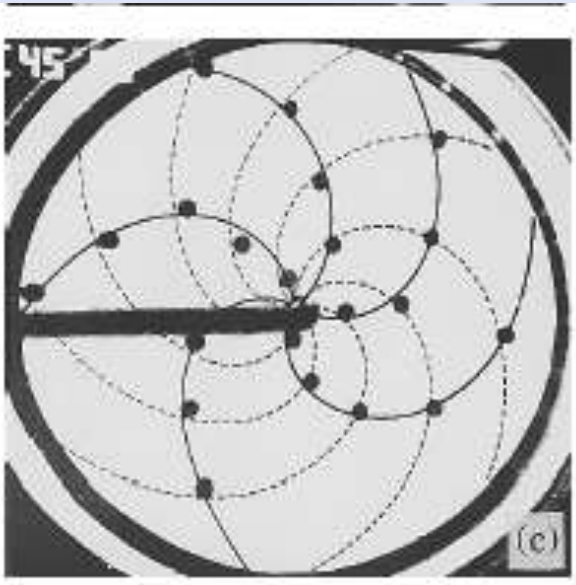


FIG. 2. Sketch of the experimental apparatus. Drops of ferrofluid are used to simulate the primordia. The drops (of volume $v \approx 10\,\text{mm}^3$) fall with a tunable periodicity T at the centre of a horizontal teflon dish. The vertical magnetic field H is created by two coils in the Helmholtz position. The dipoles are radially advected with velocity V by the magnetic field gradient (controlled by the currents I_1 and I_2 in the two coils). The drops ultimately fall into a deep ditch at the periphery, designed to prevent accumulation.



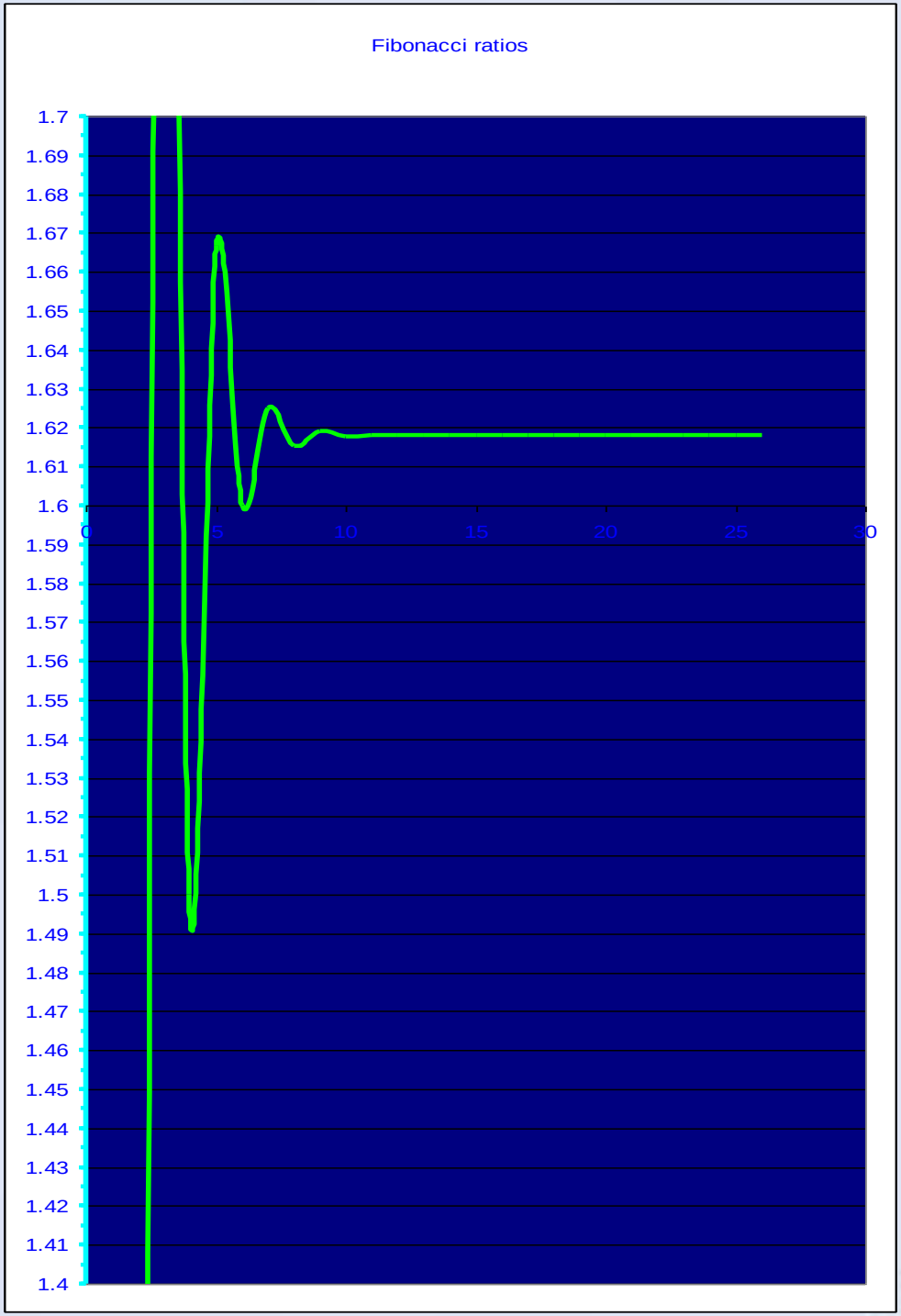
converges to ~ 137⁰ of separation...



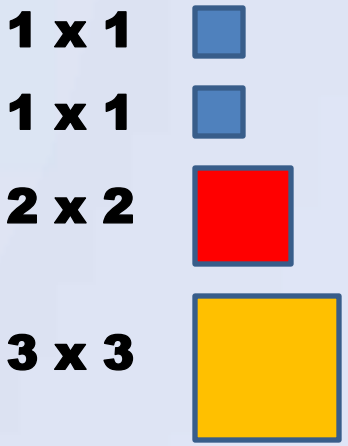


The ratio of any two consecutive Fibonacci numbers converges to ϕ!

1	
1	1
2	2
3	1.5
5	1.666666667
8	1.6
13	1.625
21	1.615384615
34	1.619047619
55	1.617647059
89	1.618181818
144	1.617977528
233	1.618055556
377	1.618025751
610	1.618037135
987	1.618032787
1597	1.618034448
2584	1.618033813
4181	1.618034056
6765	1.618033963
10946	1.618033999
17711	1.618033985
28657	1.61803399
46368	1.618033988
75025	1.618033989
121393	1.618033989

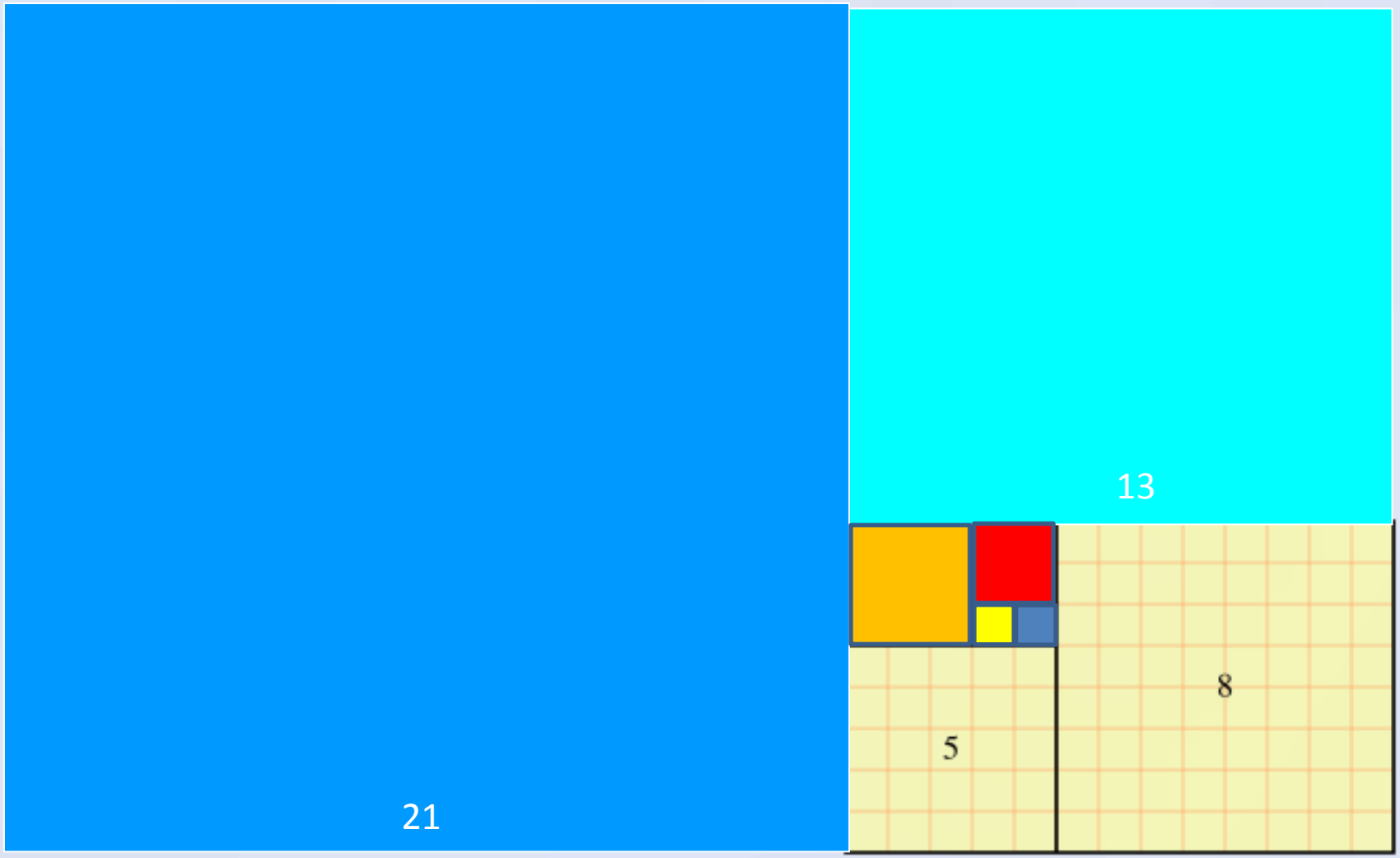


If you put together increasingly larger squares the sides of which are Fibonacci numbers, what do you come out with?



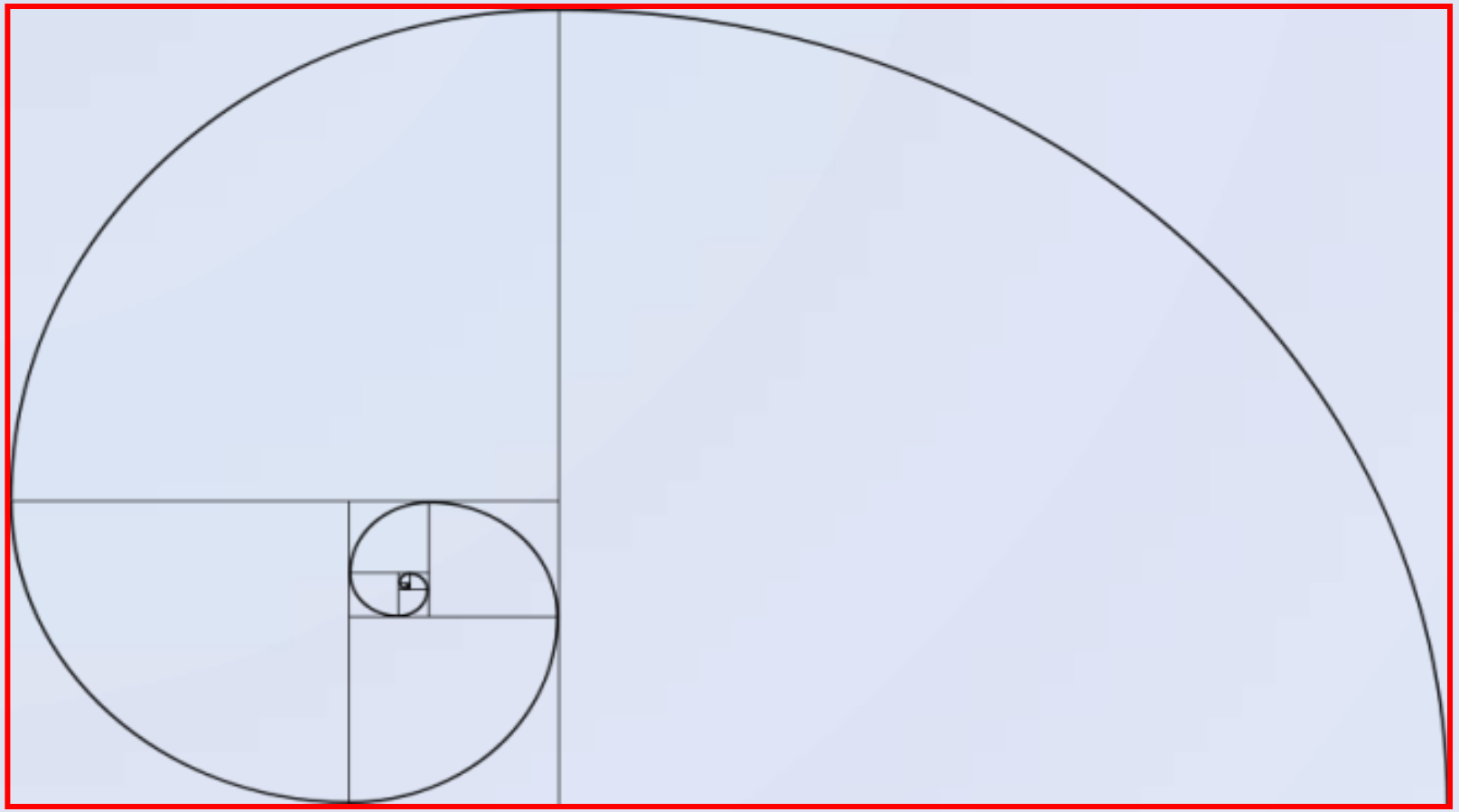
5 x 5 …etc.

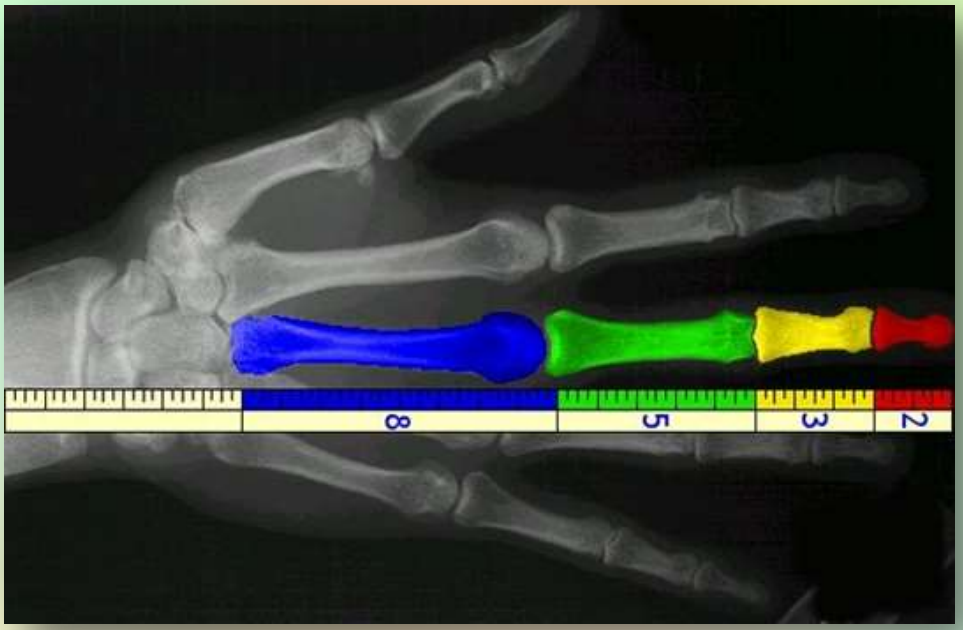
Try it yourselves and see what you get…



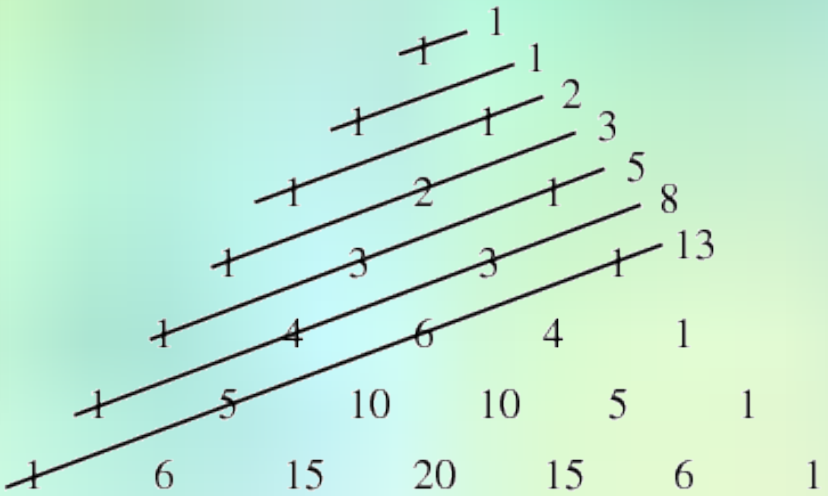
As you add more squares, you approach a Golden Rectangle whose sides are in the ratio of φ : 1

And if you draw spirals which connect the diagonals of the Fibonacci-sided squares within the Golden Rectangle, you get a Golden Spiral.



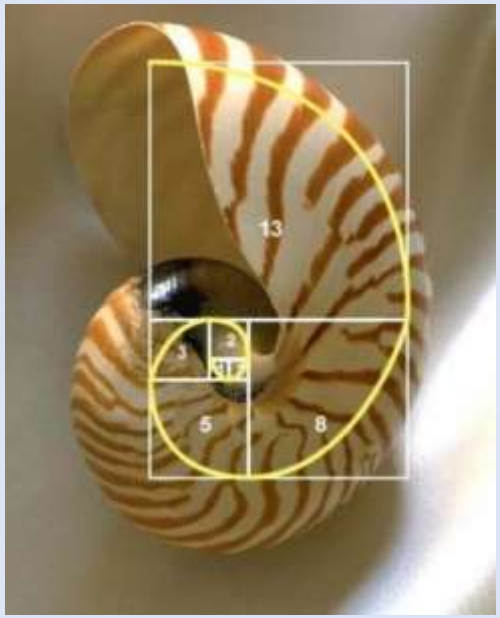


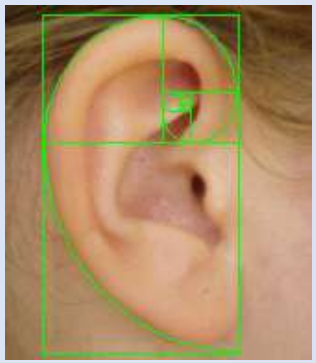
More human fascination with ϕ



binomial series coefficients

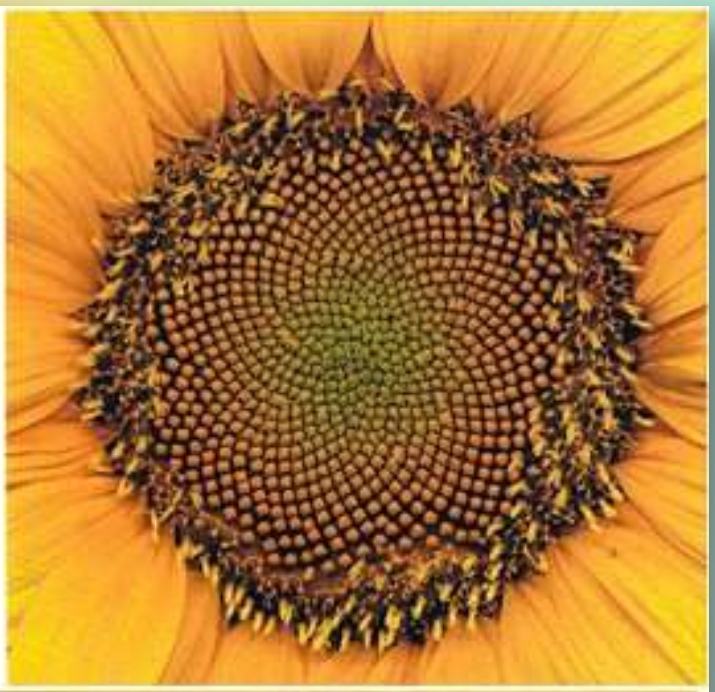
The Golden Spiral appears in numerous situations in Nature.





- **What is so special about φ, discovered by Euclid, that it should appear in Nature???**
- **Is it just our perspective?**
- **Would a civilization on a planet orbiting another star observe the same thing?**

What do you think?



Is phi symmetry or asymmetry?

or a bit of both?

symmetry = stability, laws of physics

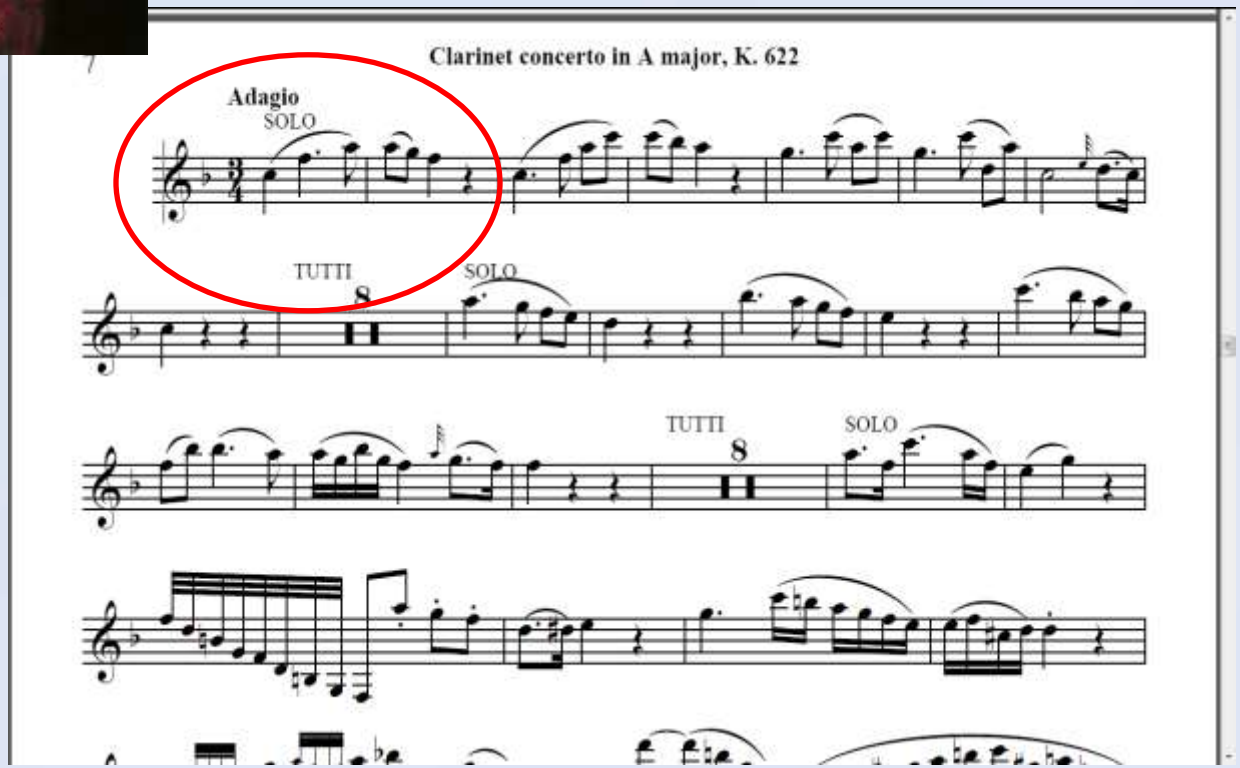
asymmetry = change, growth according to the laws of physics

Parting thoughts: A peek at things to come…

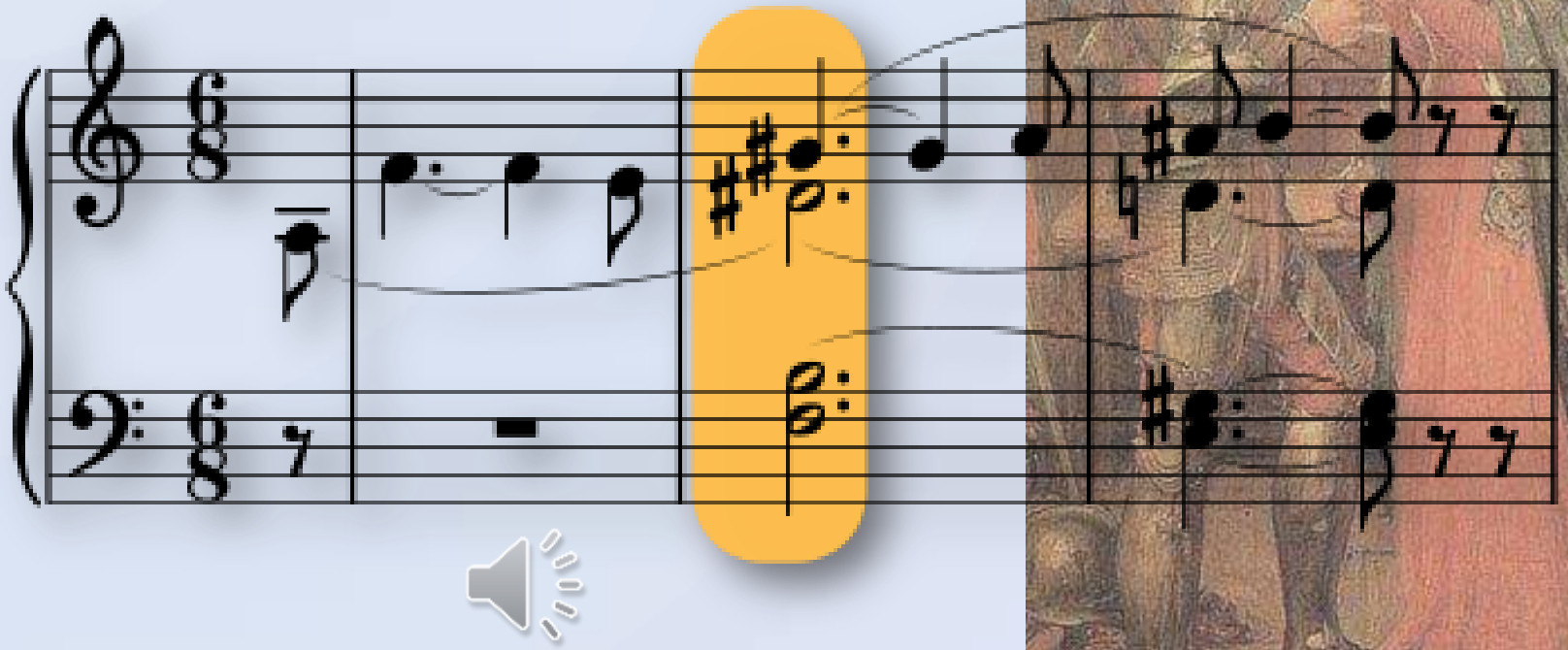
symmetry → stability

broken symmetry →movement? growth? evolution?

Mozart clarinet concerto composed in 1791



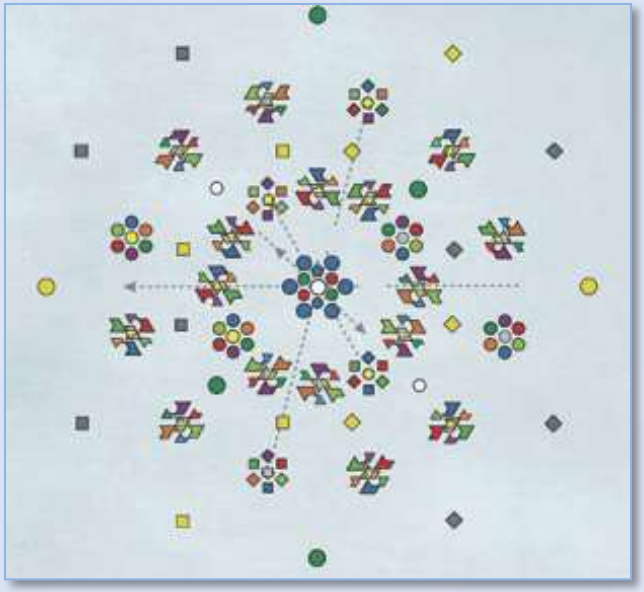
The Tristan Chord from Wagner's Tristan und Isolde



When *Tristan und Isolde* was first heard in 1865, the chord was considered innovative, disorienting, and daring. Musicians of the twentieth century often identify the chord as a starting point for the modernist disintegration of tonality. (Wikipedia)

The goals of this course:

1. To understand how Symmetry principles guide our understanding of the fundamental laws of Nature.

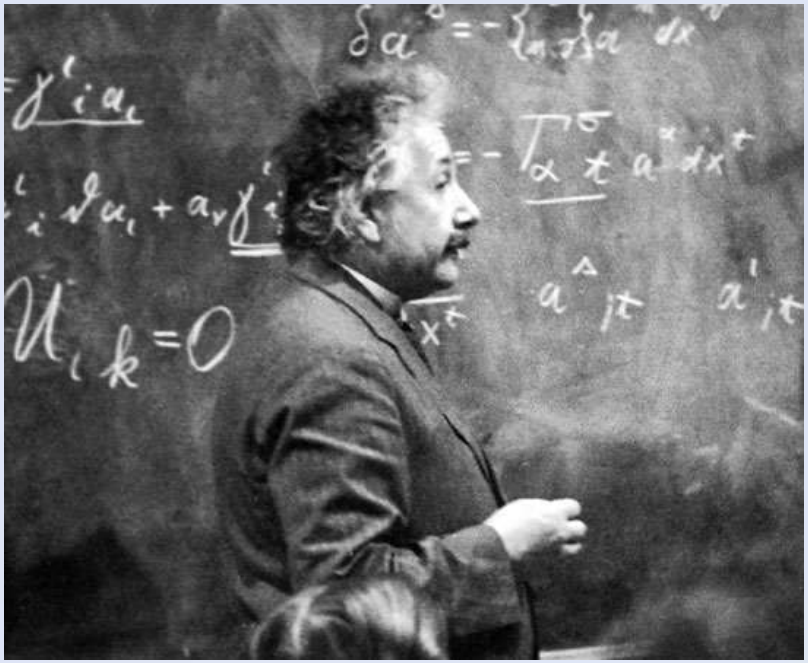


2. To use the ways of knowing available through both math and the arts to develop our intuition about how the Universe works and communicate our understanding to ourselves, each other, and the public.

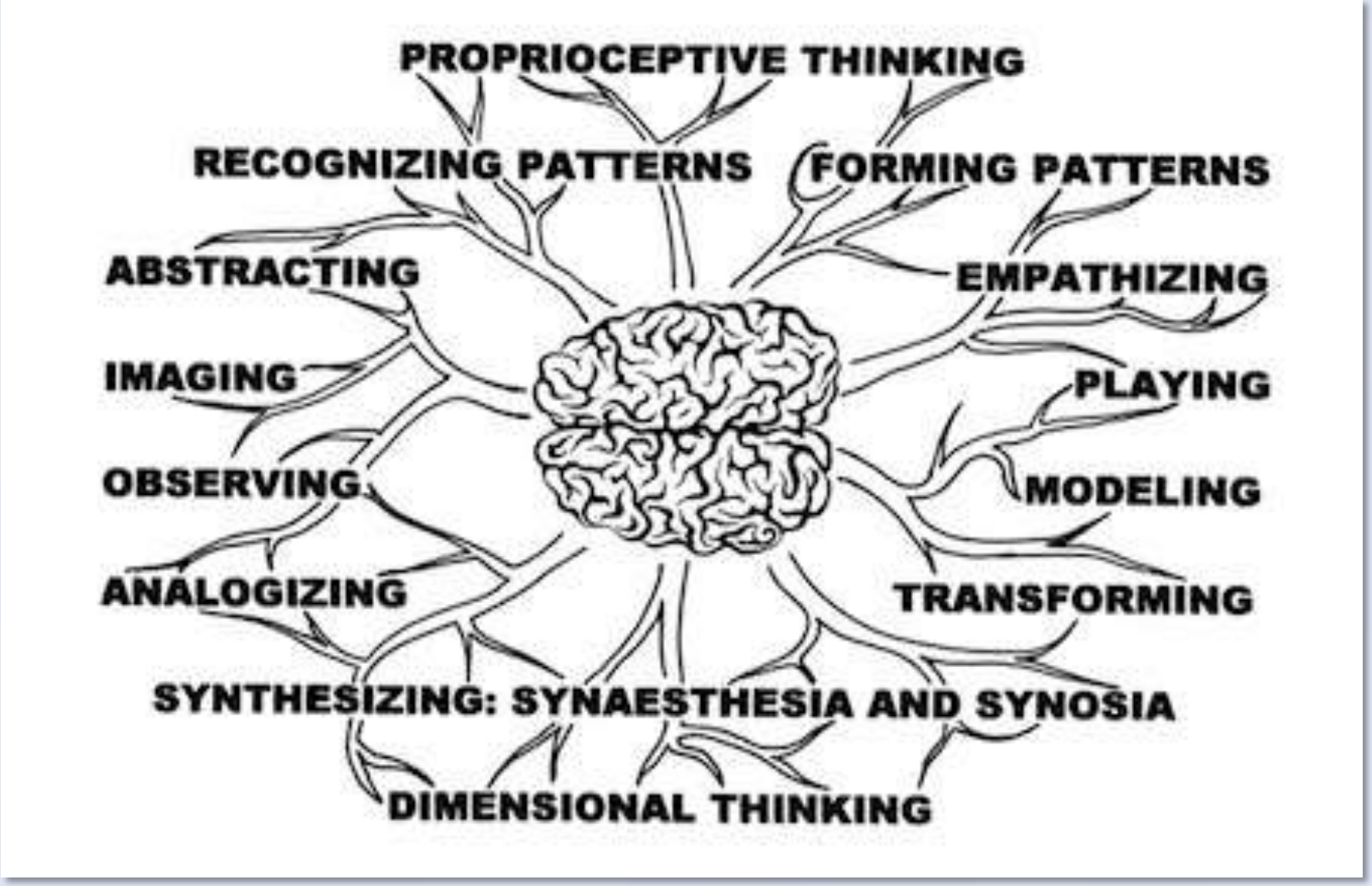
To blend the artist's and scientist's ways of knowing

"…arts and sciences are, indeed, similar enough that the methods of one can usefully be employed to make breakthroughs in the other." Robert Scott Root-Bernstein,
Source: http://artworks.arts.gov/?tag=robert-root-bernstein

"The physical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be voluntarily reproduced or combined."
Source: a letter from Einstein to mathematician Jacques Hadamard in 1945



because, in fact, that's how our brains are wired!



Source: http://artworks.arts.gov/?tag=robert-root-bernstein

First reading assignment: *Physics & Reality* by Albert Einstein

- **Ontological question: What is Reality?**
- **Epistemological question: How do we know that which we claim to know?**
- **How do YOU "visualize" concepts?**

Due next time: RR and first drawing assignment