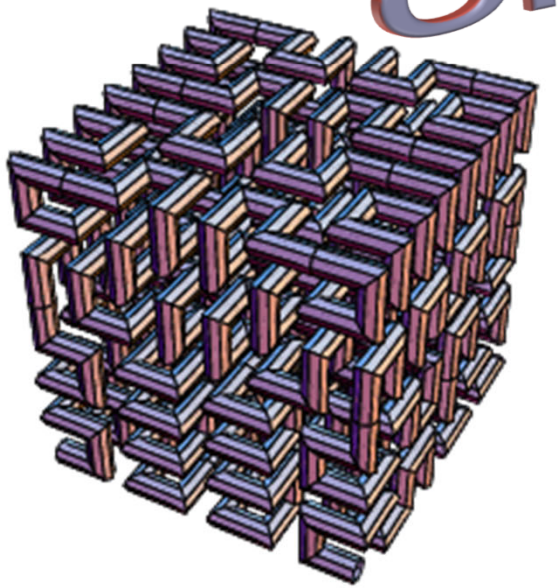
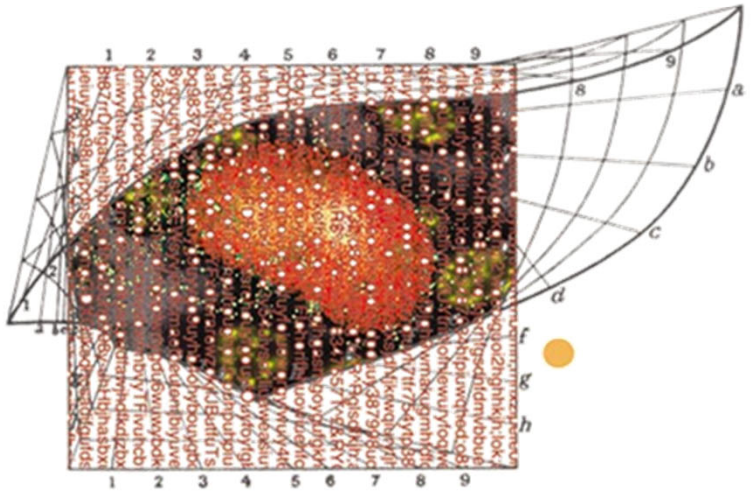
lecture 7: Modeling

Modeling Principles of Organization





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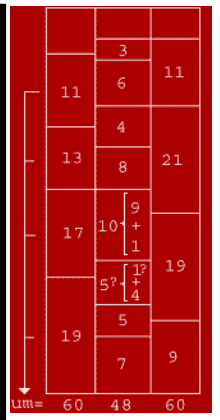
abstracting symbol mappings

Raphael's "*Plato and Aristotle*"

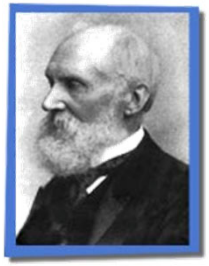
- ***Aristotle*** (384-322 BC)
  - First (??) to relate symbols more explicitly to the external world and to successively clarify the nature of the symbol-world relation.
    - Student of Plato, educated Alexander the Great
    - first to consider specific ***observable*** factors which determine *motion*.
  - In ***Physics***
    - he recognized (mathematical) ***rules*** which could describe the ***relation*** between an object's weight, the medium's density and the consequent rate of motion (fall):
      - (1) for freely falling or freely rising bodies, speed is proportional to the density of the medium.
      - (2) in forced motion, speed is proportional to the force applied and inversely proportional to the mass of the body moved
    - first time that ***observable*** quantities had been expressed in symbolic (numerical) form allowing the results of observations to be used in calculations
      - The nature of ***causation***
      - http://classics.mit.edu/Aristotle/physics.html



Ishango bone

Modeling!

"*When you can measure what you are speaking of and express it in numbers you know that on which you are discoursing. But if you cannot measure it and express it in numbers. your knowledge is of a very meagre and unsatisfactory kind*". Lord Kelvin



Lebombo bone

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symbol-world relation

- Galileo (1564-1642)
  - Progressive dissociation of the symbols from objects
    - The interrelationships among signs themselves studied quite apart from the relations among the objects they represent
      - Previously, symbols were still generally regarded as inherent properties of the referent objects themselves
      - Aristotle's *Physics* postulated certain primary qualities/elements such as "Fire". Galileo regards "primary" properties as only those that can be mathematically quantified, such as size, shape and motion.
- Newton (1643-1727)
  - Extends process of abstraction
    - Distinguishes between symbols
      - Arising from *observation*
        - represent initial conditions
      - Arising from *symbol relations*
        - representing laws which govern the subsequent motion.

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Heinrich Hertz (1857-1894)

- Some facts about Hertz
  - First to broadcast and receive radio waves
  - Established that light is a form of electromagnetic radiation.
  - His name is associated with the SI unit for frequency
- *Principles of Mechanics* (1894)
  - Goal was to purge physics of mystical, undefined, unmeasured entities
    - such as force (which one can infer but not measure)
  - Physical theories to be based only on measurable quantities
    - the results of *measurements* are symbols.
    - Physical theory becomes about building *relationships* among observationally-derived symbols: ***models***
      - what Hertz called "images."

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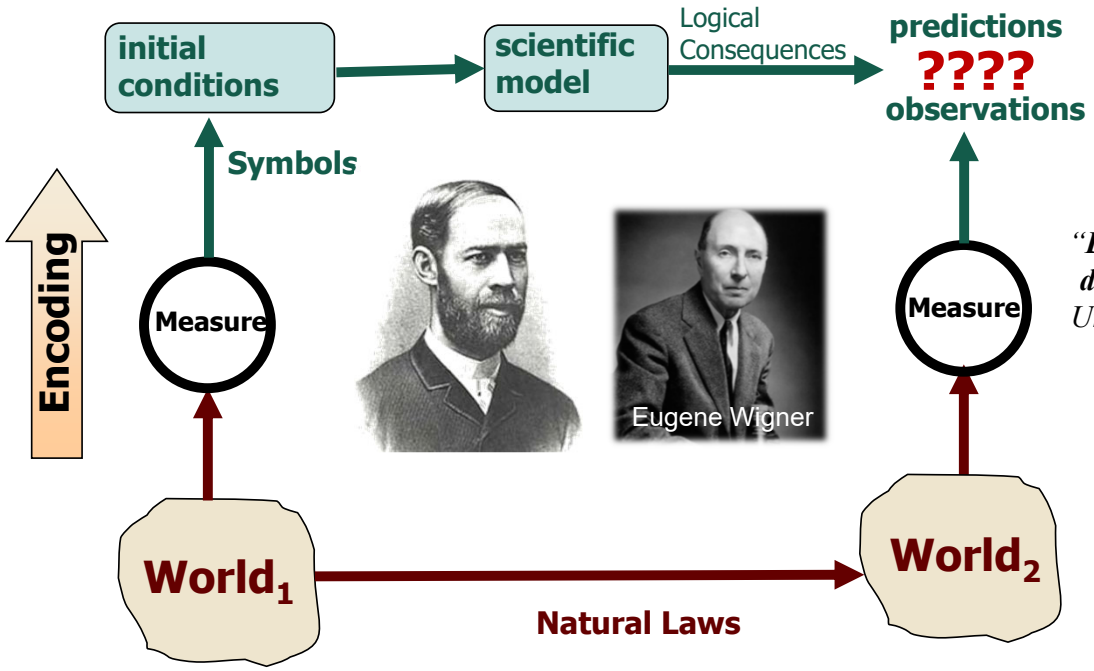
Hertzian scientific modeling paradigm



*"**Every empirical law has the disquieting quality that one does not know its limitations**." E. Wigner [1957] in "The Unreasonable Effectiveness of Mathematics in the Natural Sciences"*

"The most direct and in a sense the most important problem which our conscious knowledge of nature should enable us to solve is the ***anticipation of future events***, so that we may arrange our present affairs in accordance with such anticipation". (Hertz, 1894)

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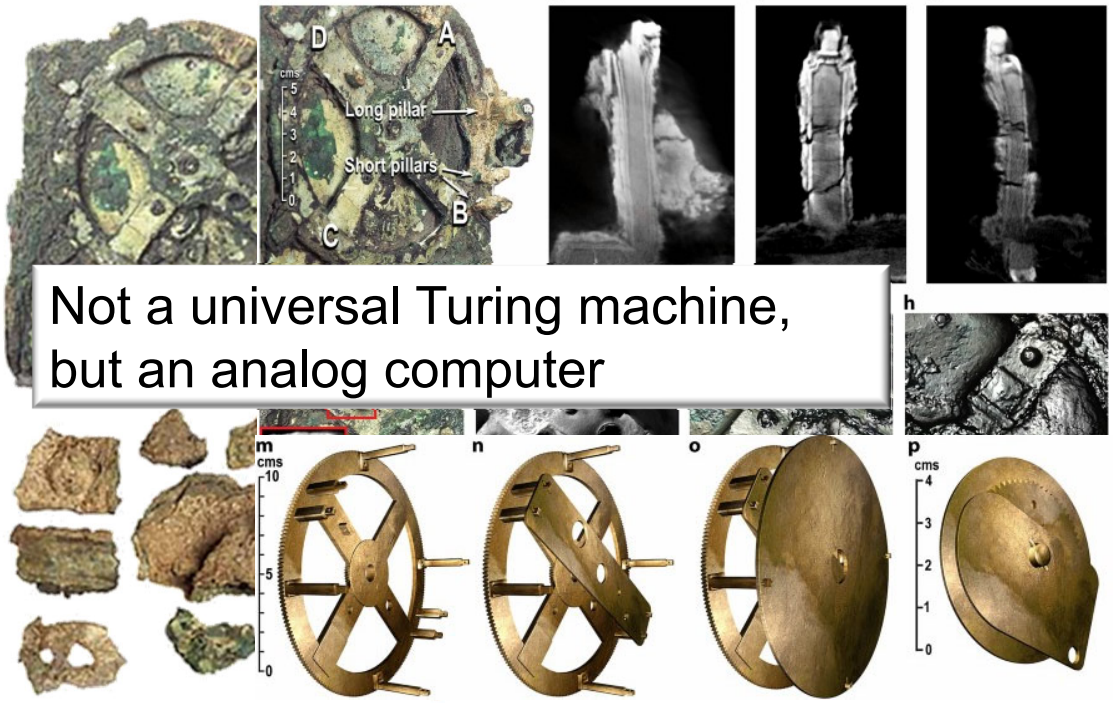
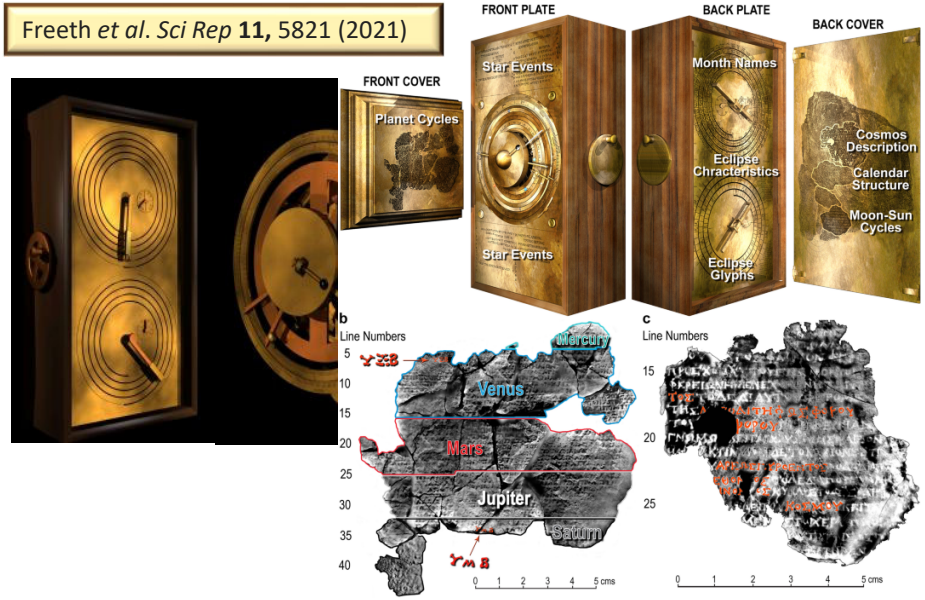
2,000-year-old astronomical calculator

- bronze mechanical **analog** computer
  - discovered more than 100 years ago in a Roman shipwreck, was used by ancient Greeks to display astronomical cycles.
- built around the end of the second century BC to calculate astronomical positions
- With imaging and high-resolution X-ray tomography to study how it worked.
  - complicated arrangement of at least 30 precision, hand-cut bronze gears housed inside a wooden case covered in inscriptions.
  - technically more complex than any known device for at least a millennium afterwards.



Not a universal Turing machine, but an analog computer

Freeth *et al*. *Sci Rep* **11,** 5821 (2021)



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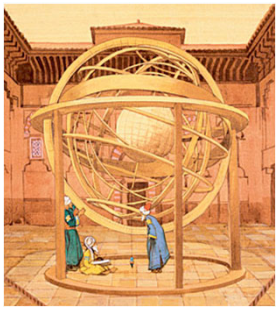
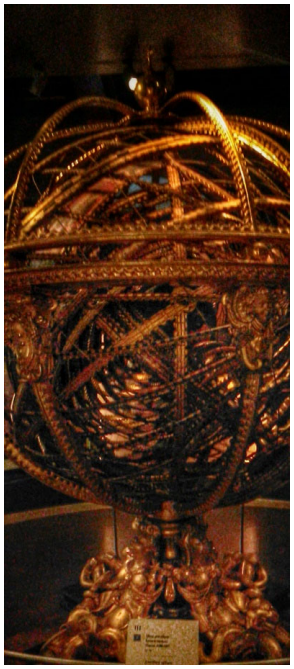
other models

Stonehenge (3000 BC)

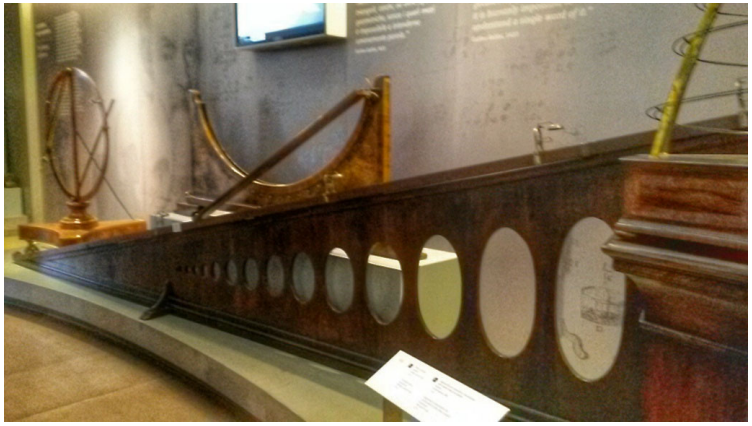


Abbas ibn Firnas (IX)

Mariner's Astrolabe (XV)



Modern Science
(16-17th century)



XVIII to XIX

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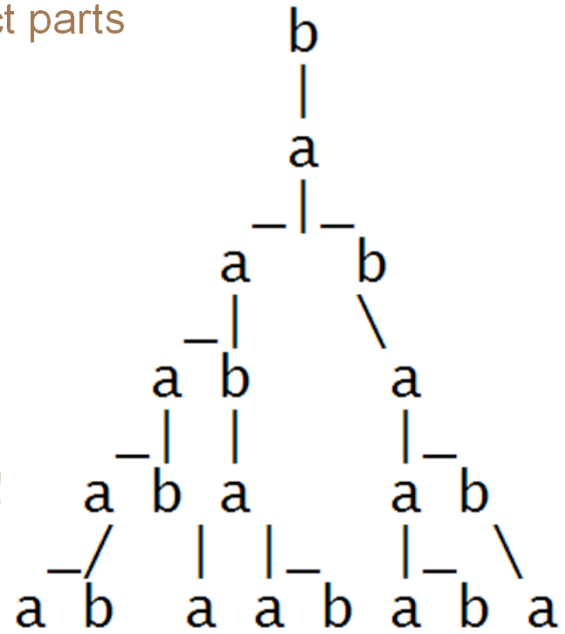
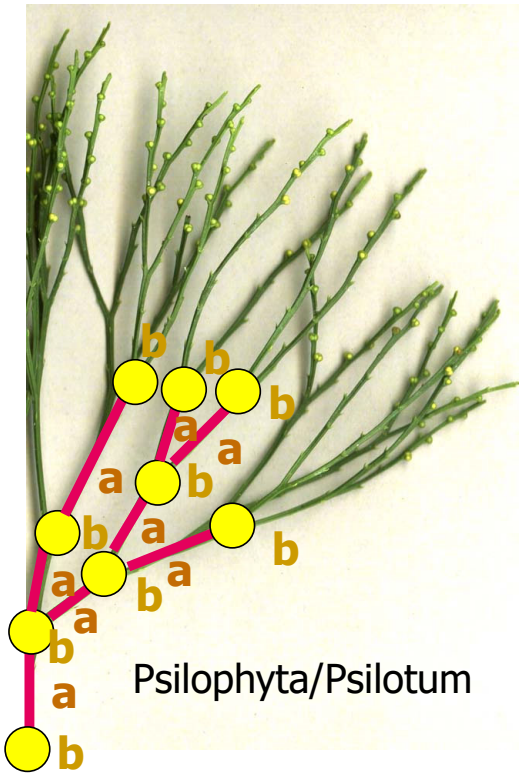
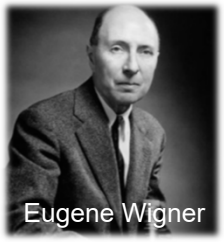
Building models

Lebombo bone

- What do you see?
  - Plants typically ***branch*** out
  - How can we ***model*** that?
    - Observe the distinct parts
      - Color them
      - Assign *symbols*
    - Build Model
      - Initial State: b
      - b -> a
      - a -> b
      - a -> ba
    - Does not model all!







Eugene Wigner

Heinrich Hertz

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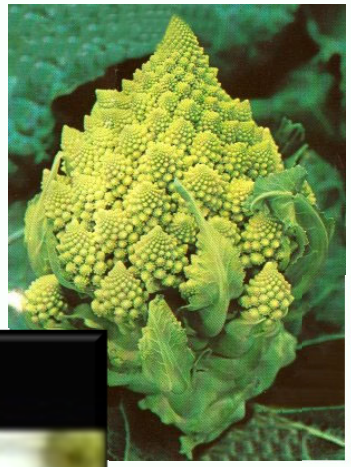
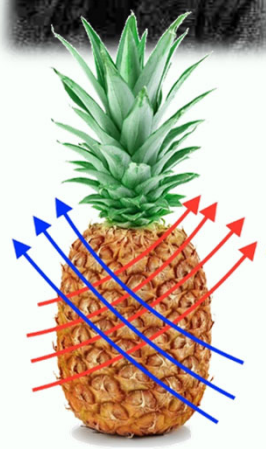
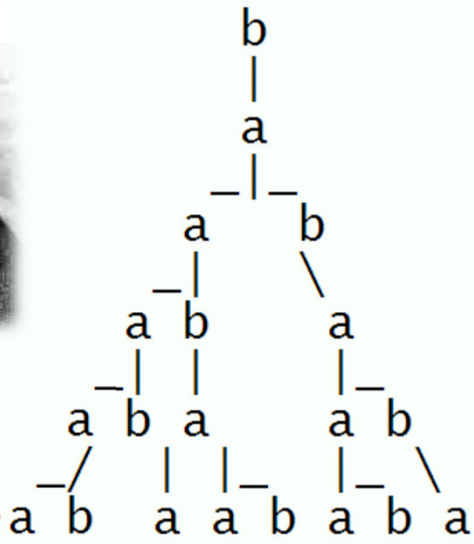
our first model

- ***Rewriting*** production rules
  - Initial State: b
  - b -> a
  - a -> ba
    - n=0 : b
    - n=1 : a
    - n=2 : ba







acci Sequence

09/modeling-systems.html
om/fractals/romanesco.htm

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Mathematics

Language

3.

1415926535 8979323846 2643383279
5028841971 6939937510 5820974944
5923078164 0628620899 8628034825
3421170679 8214808651 3282306647
0938446095 5058223172 5359408128
4811174502 8410270193 8521105559
6446229489 5493038196 4428810975
6659334461 2847564823 3786783165
2712019091 4564856692 3460348610
4543266482 1339360726 0249141273
7245870066 0631558817 4881520920
9628292540 9171536436 7892590360
0113305305 4882046652 1384146951
9415116094 3305727036 5759591953
0921861173 8193261179 3105118548
0744623799 6274956735 1885752724
8912279381

Is The

Of Nature

When I was a kid my mother told me
never to stare into the centre of the sun.
So once, when I was 6,
I did

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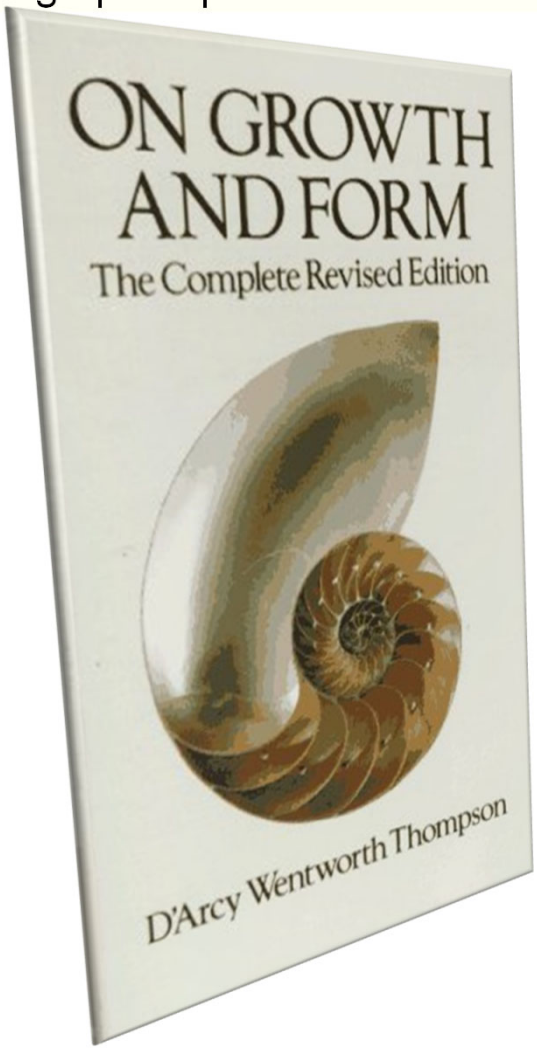
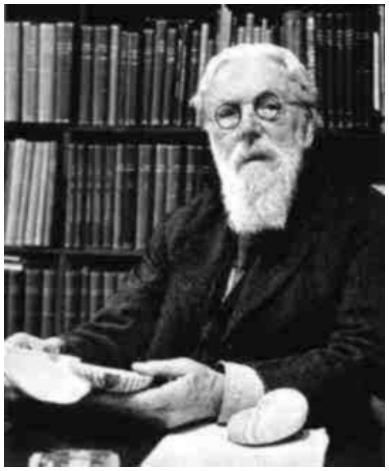
design principles



- D'Arcy Wentworth Thompson (1860 - 1948)
  - *On Growth and Form* (1917), laid the foundations of bio-mathematics
    - Equations to describe static patterns of living organisms
      - Shells, cauliflower head, etc.
    - Transformations of form changing a few parameters



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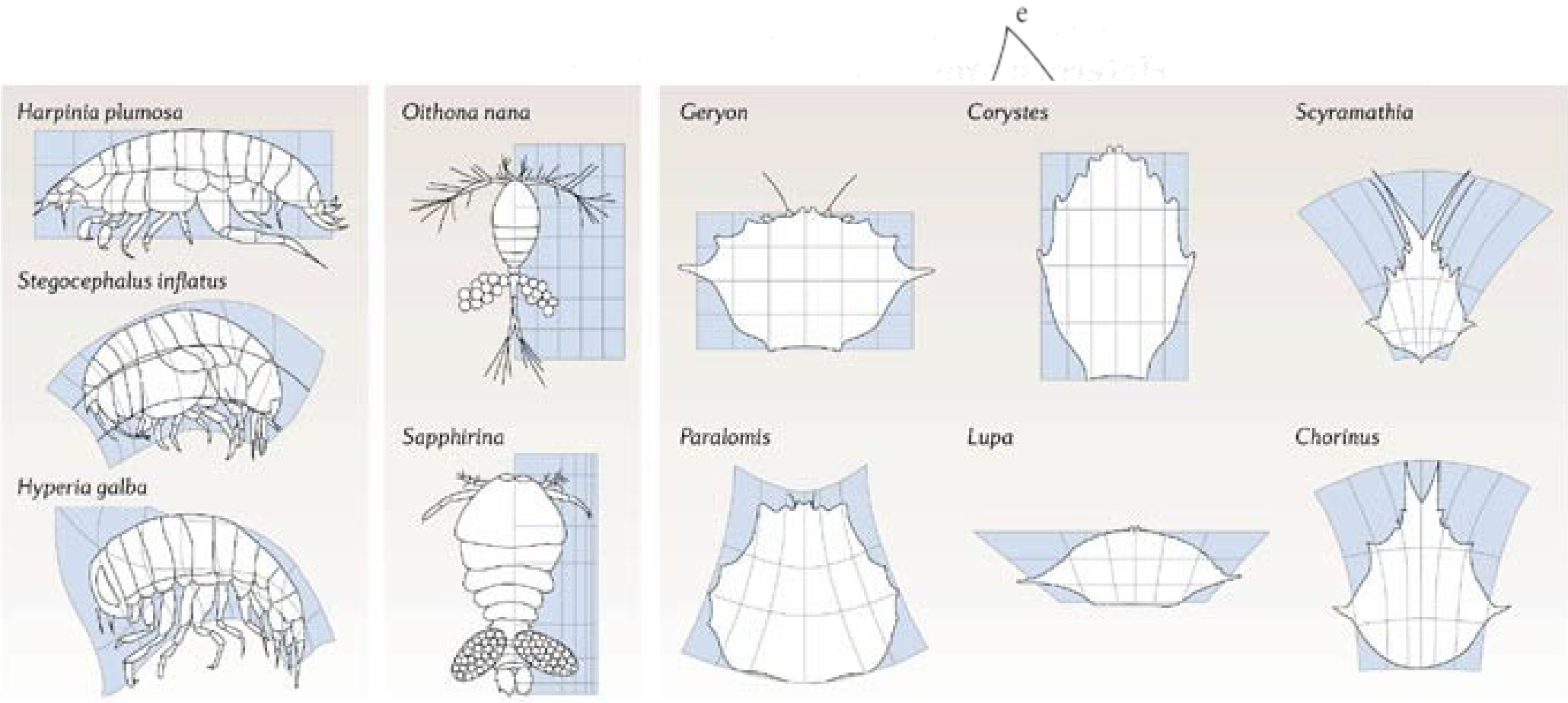

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Arthur, Wallace. "D'Arcy Thompson and the theory of transformations." *Nature Reviews Genetics* 7.5 (2006): 401-406.

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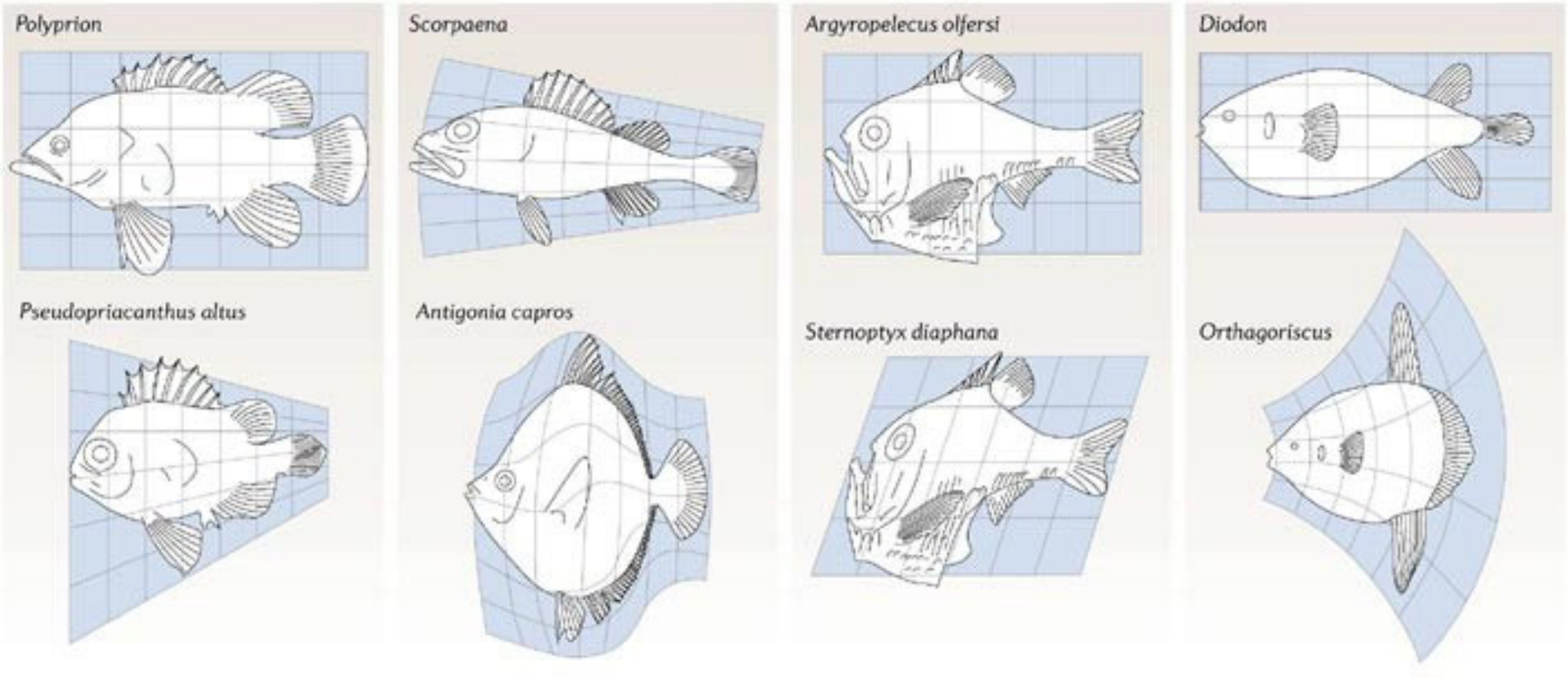
D'Arcy Thompson



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Arthur, Wallace. "D'Arcy Thompson and the theory of transformations." *Nature Reviews Genetics* 7.5 (2006): 401-406.

Fig. 517. *Argyropelecus Olfersi.* Fig. 518. *Sternoptyx diaphana.*

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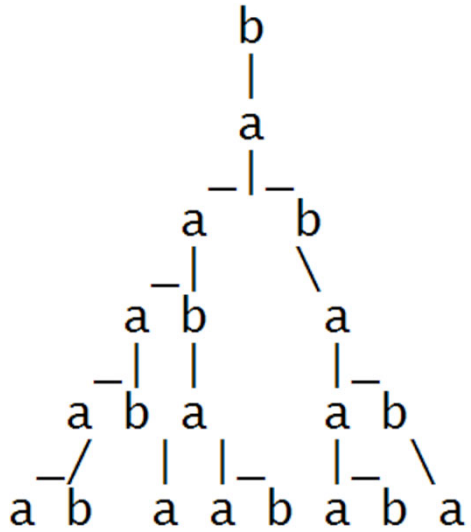
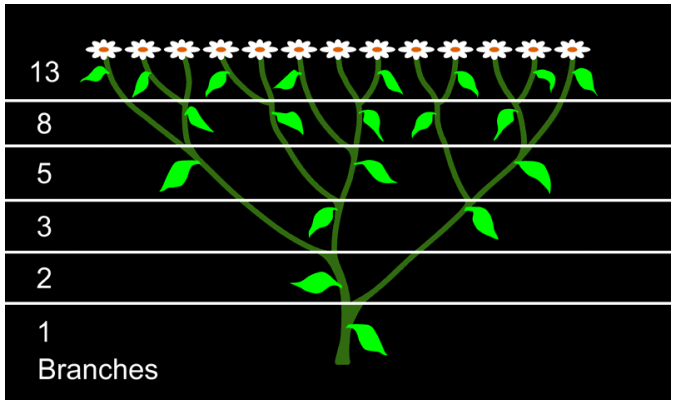
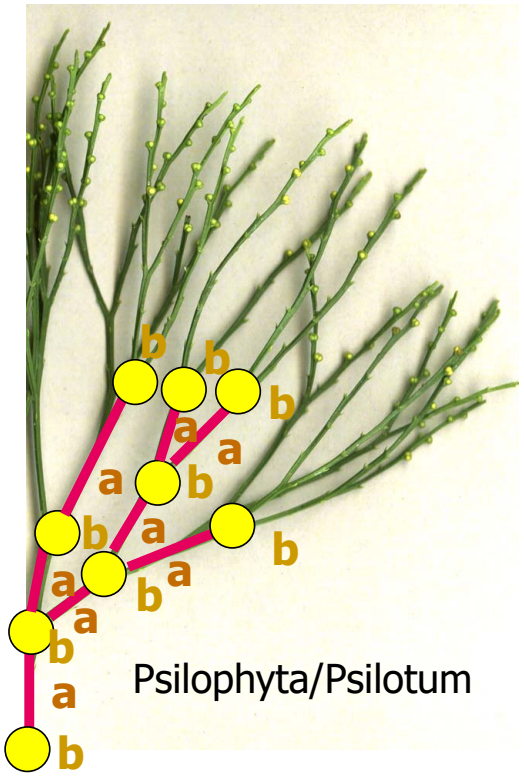
branching as a model (a general system?)

- An Accurate Model
  - Requires
    - Varying angles
    - Varying stem lengths
    - randomness
  - The Fibonacci Model is similar
    - Initial State: b
    - b -> a
    - a -> ab
  - *sneezewort*







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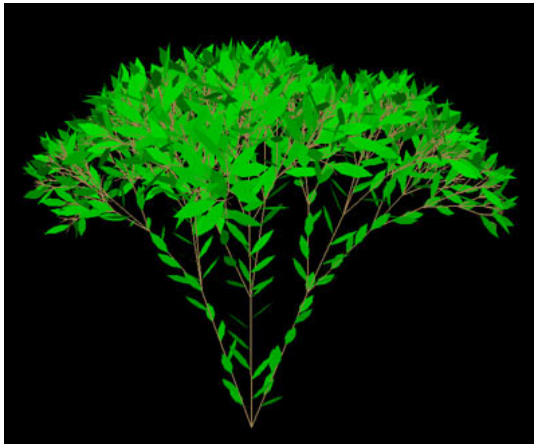
Aristid Lindenmeyer

- Mathematical formalism proposed by the biologist Aristid Lindenmayer in 1968 as a foundation for an axiomatic theory of biological development.
  - applications in computer graphics
    - Generation of fractals and realistic modeling of plants
  - Grammar for rewriting Symbols
    - Production Grammar
    - Defines complex objects by successively replacing parts of a simple object using a set of recursive, rewriting rules or productions.
      - Beyond one-dimensional production (Chomsky) grammars
      - Parallel ***recursion***
      - Access to computers



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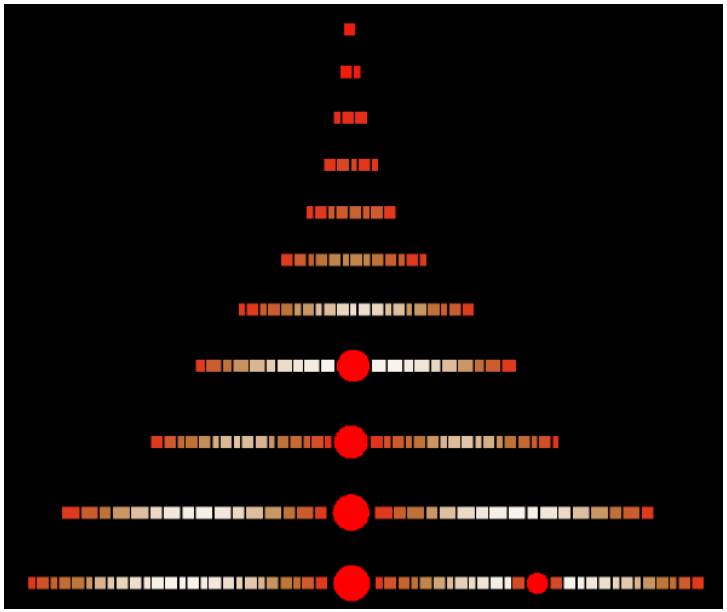
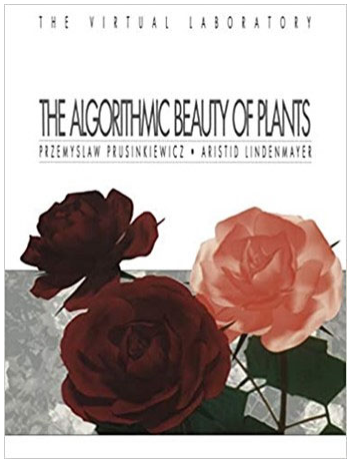
example

```
#define CH 900  /* high concentration */
#define CT 0.4  /* concentration threshold */
#define ST 3.9  /* segment size threshold */
#include H      /* heterocyst shape specification */
#ignore f ~ H

ω  :  -(90)F(0,0,CH)F(4,1,CH)F(0,0,CH)
p1 :  F(s,t,c) :  t=1 & s>=6 →
                  F(s/3*2,2,c)f(1)F(s/3,1,c)
p2 :  F(s,t,c) :  t=2 & s>=6 →
                  F(s/3,2,c)f(1)F(s/3*2,1,c)
p3 :  F(h,i,k) < F(s,t,c) > F(o,p,r) :  s>ST|c>CT →
                  F(s+.1,t,c+0.25*(k+r-3*c))
p4 :  F(h,i,k) < F(s,t,c) > F(o,p,r) :  !(s>ST|c>CT) →
                  F(0,0,CH) ~ H(1)
p5 :  H(s) :  s<3 → H(s*1.1)
```





convenient tool for expressing developmental models with ***diffusion of substances***. pattern of cells in *Anabaena catenula* and other blue-green bacteria

From: P. Prusinkiewicz and A. Lindenmayer [1991]. *The Algorithmic Beauty of Plants*.

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