UCSD
Center for Human Development Seminar

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The return of the laws of form and (some) perfection in language

A methodological priority:

- *"The primary task of the biologist is to discover the set of forms that are likely to appear… [for] only then is it worth asking which of them will be selected."*
- (P. T. Saunders, (ed.). (1992). *Collected Works of A. M. Turing: Morphogenesis*. London: North Holland:xii).

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Re-thinking evolution

- Gregory C. Gibson in Science (2005), reviewing a book by Andreas Wagner on robustness and evolvability, says:
- *"[this book] contributes significantly to the emerging view that natural selection is just one, and maybe not even the most fundamental, source of biological order".*
- Gibson, G. (2005). SYSTEMS BIOLOGY: The Origins of Stability. *Science, 310* (5746), 237.
- Gibson is the William Neal Reynolds Distinguished Professor of Genetics, North Carolina State University (PhD, University of Basel, Switzerland. Postdoctoral, Stanford University)

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Minimalism

- *"We can regard an account of some linguistic phenomena as principled insofar as it derives them by efficient computation satisfying interface conditions. A very strong proposal, called "the strong minimalist thesis", is that all phenomena of language have a principled account in this sense, that language is a perfect solution to interface conditions, the conditions it must satisfy to some extent if it is to be usable at all. If that thesis were true, language would be something like a snowflake, taking the form it does by virtue of natural law, in which case UG would be very limited".* (Chomsky in press)

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My line of argument

- The laws of form are strictly linked to Chomsky's (2005) "third factor" in language design
- Not specific to language and not even specific to biology
- The Strong version of the Minimalist Program hypothesizes that NS is an optimal solution in solving the problem of the interfaces
- The Minimalist Program can be on the right track or can be on a wrong track
- (I think it's on the right track)
- However
- The central importance of general principles of optimal design would **not** be the only instance we find in biology (pace Pinker and Jackendoff)

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The return of the laws of form

The return of the laws of form

- Non-genomic nativism (the perfection of neuronal connections)
- The segregation into grey and white matter
- Fractal geometry (minimal energy dispersion, maximal space-filling and constant size of the terminal branches)
- The scaling law of locomotion
- Optimal foraging
- Optimal plant vascularization
- Optimal wing stroke in birds
- Optimal control of birdsongs

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D'Arcy Wentworth Thompson (1860-1948) on "The Laws of Form" (1917)

- Biologists have overemphasized the role of evolution, and underemphasized the roles of physical and mathematical laws in shaping the form and structure of living organisms.
- The Miraldi angle, the Fibonacci series, the golden ratio and the logarithmic spiral.
- *"….the beautiful regularity of the bee's architecture is due to some automatic play of the physical forces."* (D'Arcy Thompson)

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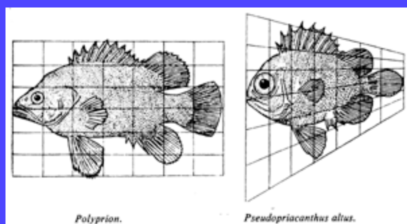
D'Arcy Thompson's famous grids



A simple mathematical transformation converts one form into the other

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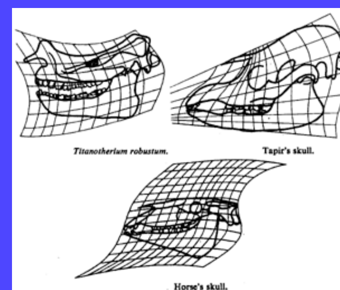

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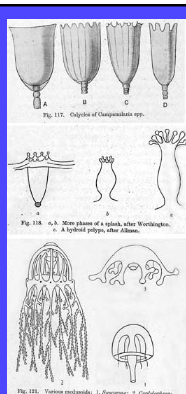
Plant forms

Splashes and polyps

Medusoids



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Enter the mighty Turing

- A. M. Turing *The Chemical Basis of Morphogenesis* (1952)
- Reaction-diffusion processes
- *"A system of chemical substances, called morphogens, reacting together and diffusing trough a tissue, is adequate to account for the main phenomena of morphogenesis"*
- *Th[is] investigation is chiefly concerned with the onset of instability".*
- A sphere and then gastrulation
- An isolated ring of cells and then stationary waves
- A two-dimensional field and then dappling

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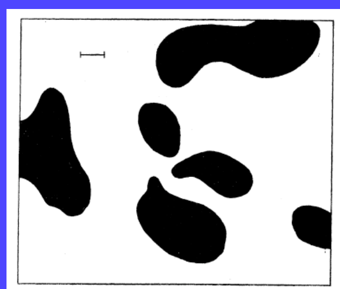
Dappling in 2D as the result of one morphogen



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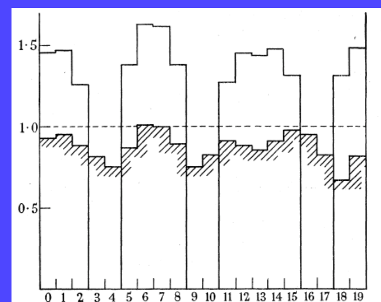
Concentration of one morphogen (Y) in a ring of cells



"Variety with quick cooking"

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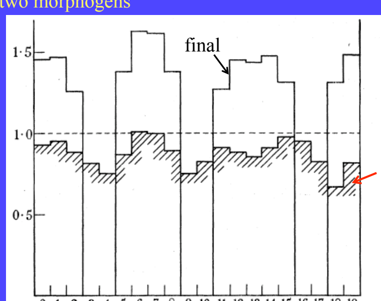
Concentration of one morphogen (Y) in a ring of cells
with two morphogens

Initial →



Transient

A stable "four lobes" configuration

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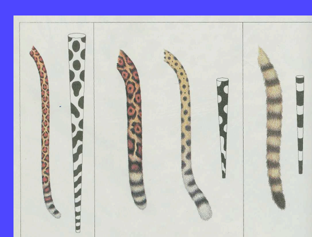
Spots and Stripes

- Activator and inhibitor factors with different diffusion rates can interact to produce regular spots/stripes (Turing 1952).



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Biological instances

- The case of the sea-anemone *Hydra* and of the leaves of the woodruff (*Asperula odorata*)

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Non-genomic nativism

Christopher Cherniak et al.
University of Maryland

Neuro-rationalism

Ever since 2004

Cherniak, C., Z. Mokhtarzada, R. Rodriguez-Esteban, & K. Changizi. (2004). Global optimization of cerebral cortex layout. *Proc Natl Acad Sci U S A, 101* (4), 1081-1086.

Combinatorial network optimization

- Minimization of connection costs among interconnected components in a system.
- Such wiring minimization can be observed at various levels of nervous systems, invertebrate and vertebrate, from placement of the entire brain in the body down to the subcellular level of neuron arbor geometry.
- In some cases, **the minimization appears either perfect, or as good as can be detected with current methods** -- a predictive success story.
- These instances of optimized neuroanatomy include candidates for some of the most complex biological structures known to be derivable "for free, directly from physics"
- i.e., **purely from simple physical energy minimization processes**.
- Such a "Physics suffices" picture for some biological self -organization directs attention to innate structure via non -genomic mechanisms.

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Component Placement Optimization

- For the macaque, **fewer than one in a million of all alternative layouts** conform to the adjacency rule better than the actual layout of the complete macaque set.
- Each of the cortex systems analyzed by Cherniak et al. shows better goodness of fit to an "*if connected, then adjacent*" hypothesis than to the converse hypothesis.
- Better than the best designed micro-chip
- Cherniak, C., Z. Mokhtarzada, R. Rodriguez-Esteban, & K. Changizi. (2004). Global optimization of cerebral cortex layout. *Proc Natl Acad Sci U S A, 101* (4), 1081-1086.

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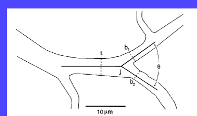

Neuron arbor junction (cat retina ganglion cell dendrite).
(a) Branch and trunk diameters conform to $t^3 = b_1^3 + b_2^3$,
(b) a fluid-dynamic model for minimum internal wall-drag of pumped flow (laminar regime).
(b) In turn, angle θ conforms to the "triangle of forces" law, a cosine function of the diameters: $\cos\theta = (t^2 - b_1^2 - b_2^2) / 2b_1b_2$.
This yields the minimum volume for a Y-tree junction. (Cherniak et al, 1999)
So, "Neuron arbor junctions act like flowing water."

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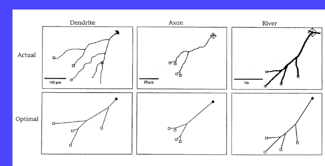

Complex biological structure arising "for free, directly from physics". "Instant arbors, just add water."
In each case, from micron to meter scale, neural and non-neural, living and non-living, the actual structure is within a few percent of the minimum-volume configuration shown.

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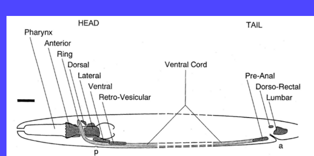

C. Elegans ganglion components: their body locations and schematized shapes.

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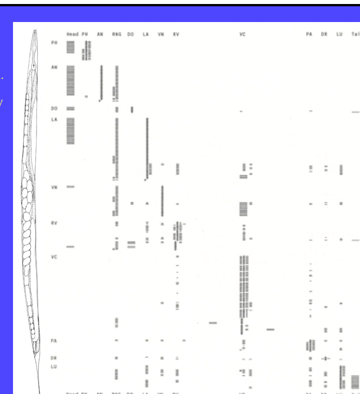
Complete ganglion-level connectivity map for *C. elegans* nervous system. (Apparently, the first depiction of approximately complete connectivity of a nervous system down to synapse level.) Each horizontal microline represents one of the 302 neurons.
Horizontal scaling: ~ 100x.
This actual ganglion layout requires **the least total connection length of all ~ 40 million alternative orderings.**
(Cherniak, 1994a)



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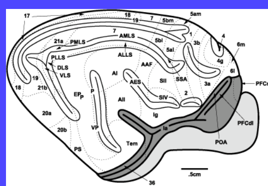

Cerebral cortex of cat. (Lateral aspect; rostral is to right.)
Placement of 39 interconnected functional areas of visual, auditory, and somatosensory systems (in white).
Exhaustive search of samples of alternative layouts suggests this actual layout ranks **at least in the top 100 billionth of all possible layouts** with respect to adjacency-cost of its interconnections.
(Cherniak et al, 2004) -- "Best of all possible brains"?

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More optimal brain design

- The segregation of the brain into gray and white matter is shown to be a natural consequence of **minimizing conduction delay** in a highly interconnected neuronal network.
- A model relating the optimal brain design to the basic parameters of the network, such as the numbers of neurons and connections between them, as well as wire diameters.
- The theory makes testable predictions
- Confirmed by anatomical data on the mammalian neocortex and neostriatum, the avian telencephalon, and the spinal cord in a variety of species (of mammals and birds)
- Wen, Q., & D. B. Chklovskii. (2005). Segregation of the brain into grey and white matter: A design minimizing conduction delays. *PLoS Computational Biology*, *1* (7 (December)/e78), 0617-0630.

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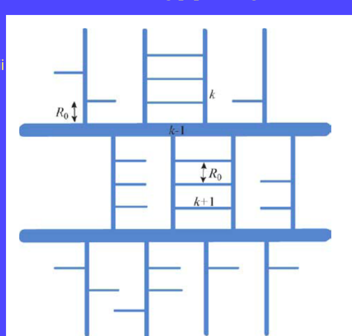
Branching pipe design

Wen & Chklovskii (2005)



R_0 = Distance between highest order branches

k = branch order

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The basic underlying problem

- Of course we need genes
- And plenty of them
- The issue is:
- What, exactly, do we need genes **for**?
- Non-genomic nativism must be complemented with genomic nativism

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An immense search space

- The key problems of network optimization theory are NP-complete,
- hence exact solutions in general are computationally intractable.
- For example, blind trial and error exhaustive search for the minimum-wiring layout of a 50 component system (such as all areas of a mammalian cerebral cortex), even at a physically unrealistic rate of one layout / picosecond, would still require **more than the age of the Universe** (Cherniak, 1994).
- Thus, to avoid Universe-crushing costs, natural selection cannot possibly have explored these possibilities at random.

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The fourth dimension of living systems

The "fourth dimension" of living systems

- Body sizes vary between 10^{-13} grams (bacteria) to 10^{8} grams (whales)
- That is: 21 orders of magnitude
- How do exchange surfaces and internal rates of transport scale?
- **Tradeoff:** Maximize inner and outer exchange surfaces but minimize distances of internal transport (maximize rates of transport)
- The entire circulatory system of a human body (capillaries notably included) is 60 thousand miles.
- The diameter of capillaries is an **invariant** in the realm of vertebrates
- Metabolic rate scales as the 3/4th power of mass

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Paradigm instances:

- General equation: $Y = Y_0(M)^b$ where b (the scaling exponent) is a simple multiple of 1/4
- M is the body mass, Y_0 a normalization constant
- Diameter of tree trunks and aortas $b = 3/8$ (therefore, for their cross section area $b = 3/4$)
- Rates of cellular metabolism and heart beat $b = -1/4$
- Blood circulation time and life span $b = 1/4$
- Whole organism metabolic rate $b = 3/4$

- Puzzle: Why multiples of 1/4 and not of 1/3?

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A hydrodynamic model under constraints of minimal energy dispersion, maximal space-filling and constant size of the terminal branches

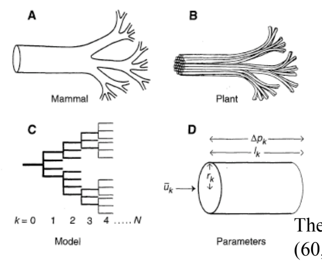


Fig. 1. Diagrammatic examples of segments of biological distribution networks: **(A)** mammalian circulatory and respiratory systems composed of branching tubes; **(B)** plant vessel-bundle vascular system composed of diverging vessel elements; **(C)** topological representation of such networks, where k specifies the order of the level, beginning with the aorta ($k = 0$) and ending with the capillary ($k = N$); and **(D)** parameters of a typical tube at the kth level.

The perfect fractal
(60,000 miles)

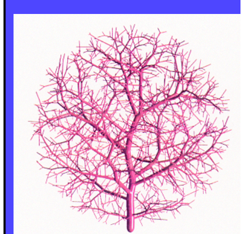
West, G., J. Brown, and B. J. Enquist. (1997). "A general model for the allometric scaling laws in biology." Science **276**: 122-126.

Empirical fit of the West, Brown and Enquist 1997 fractal model

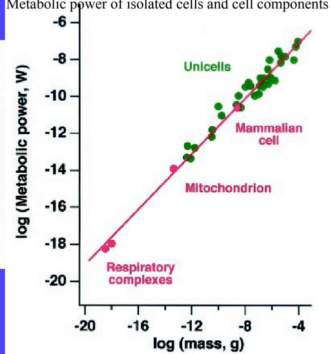
Table 1. Values of allometric exponents for variables of the mammalian cardiovascular and respiratory systems predicted by the model compared with empirical observations. Observed values of exponents are taken from (2, 3); ND denotes that no data are available.

Cardiovascular			Respiratory		
Variable	Exponent		Variable	Exponent	
	Predicted	Observed		Predicted	Observed
Aorta radius r_0	3/8 = 0.375	0.36	Tracheal radius	3/8 = 0.375	0.39
Aorta pressure Δp_0	0 = 0.00	0.032	Interpleural pressure	0 = 0.00	0.004
Aorta blood velocity u_0	0 = 0.00	0.07	Air velocity in trachea	0 = 0.00	0.02
Blood volume V_b	1 = 1.00	1.00	Lung volume	1 = 1.00	1.05
Circulation time	1/4 = 0.25	0.25	Volume flow to lung	3/4 = 0.75	0.80
Circulation distance l	1/4 = 0.25	ND	Volume of alveolus V_A	1/4 = 0.25	ND
Cardiac stroke volume	1 = 1.00	1.03	Tidal volume	1 = 1.00	1.041
Cardiac frequency ω	−1/4 = −0.25	−0.25	Respiratory frequency	−1/4 = −0.25	−0.26
Cardiac output $\dot{E}$	3/4 = 0.75	0.74	Power dissipated	3/4 = 0.75	0.78
Number of capillaries N_c	3/4 = 0.75	ND	Number of alveoli N_A	3/4 = 0.75	ND
Service volume radius	1/12 = 0.083	ND	Radius of alveolus r_A	1/12 = 0.083	0.13
Womersley number α	1/4 = 0.25	0.25	Area of alveolus A_A	1/6 = 0.083	ND
Density of capillaries	−1/12 = −0.083	−0.095	Area of lung A_L	11/12 = 0.92	0.95
O_2 affinity of blood P_{50}	−1/12 = −0.083	−0.089	O_2 diffusing capacity	1 = 1.00	0.99
Total resistance Z	−3/4 = −0.75	−0.76	Total resistance	−3/4 = −0.75	−0.70
Metabolic rate B	3/4 = 0.75	0.75	O_2 consumption rate	3/4 = 0.75	0.76

A fractal model of greater generality and greater elegance was then published by them in 1999



Metabolic power of isolated cells and cell components



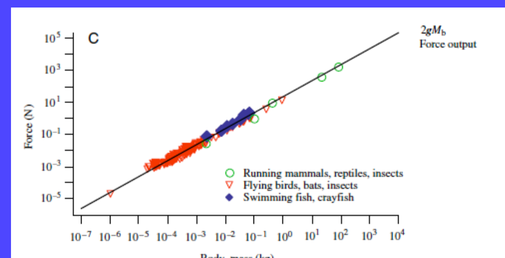
West, G.B., Woodruff, W.H. & Brown, J.H. (2002) Allometric scaling of metabolic rate from molecules and mitochondria to cells and mammals. PNAS 99, 2473-2478.

Main lessons:

- Unlike the genetic code, which has evolved only once in the history of life
- Fractal-like distribution networks have evolved many times, from bacteria to mammals
- Living beings occupy a 3-dimensional space but **have a 4-dimensional internal physiology and anatomy.**
- Evolution has added a 4-th dimension
- Natural selection has "*exploited variations on this fractal theme to produce the incredible variety of biological form and function*".
- But there were "*severe geometric and physical constraints on metabolic processes*".

Scale invariants of locomotion

Bejan, A. and J. H. Marden (2006). "Unifying constructal theory for scale effects in running, swimming and flying." The Journal of Experimental Biology **209**: 238-248.



Force output at the optimal speed across 10 orders of magnitude

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The "perfection" of foraging

- Other optimal solutions in Biological Evolution:
  - Complex foraging strategies coincide with the best solutions discovered by means of massive computer simulations (e.g. ant 'highways')
  - minimal distances, recall of locations searched, and kinds of objects retrieved, etc.
  - These remarkable capabilities cannot "extend" onto other capabilities (in other species)

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Fibonacci patterns

Leonardo of Pisa
(1170-1250)
Filius Bonacci

The series F(n) = F(n - 1) + F(n - 2)

- 0, 1, 1, 2, 3, 5, 8, 13, 21, 34, 55, 89, 144, 233, 377, 610, 987 ...
- The ratio between two successive numbers rapidly approximates the golden ratio 1.61803……..

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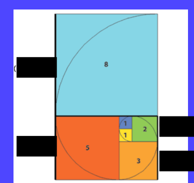
The Fibonacci spiral



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From http://ourworld.compuserve.com/homepages/DP5/pattern1.htm

Fibonacci spirals

Spiral nebulae
The Whirlpool Galaxy (M51) Seashells (Nautilus)

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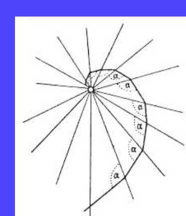

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Found everywhere

- A type of spiral found in unicellular foraminifera, sunflowers, seashells, animal horns and tusks, beaks and claws, whirlpools, hurricanes, and spiral galaxies.
- An equiangular spiral does not alter its shape as its size increases.
- Because of this remarkable property (known as self-similarity), it was known in earlier times as the ‘miraculous spiral’.
- Owing to the structure of their compound eyes, insects such as moths follow an equiangular spiral when drawn towards a candle flame. Peregrine falcons, which have eyes on either side of their heads, follow a similar spiral path when flying at their prey.

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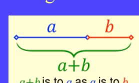
OPTIMALITY CONDITIONS: MAXIMAL SPACE FILLING

- The system is based on simple dynamics that impose constraints on arrangements to satisfy optimality conditions.
- Successive elements form at equally spaced intervals on the edge of a circle, representing the apex. They repel each other (similar to electric charges) and migrate radially. As a result, motion continues and each new element appears as far as possible from its immediate successors.

The golden ratio



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

$$\varphi = \frac{1+\sqrt{5}}{2} \approx 1.6180339887\ldots$$

The golden angle
$\Phi = 2\pi(1-\varphi) \approx 137.5^0$

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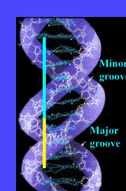
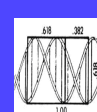
The Fibonacci series

- 1, 1, 2, 3, 5, 8…….





The golden section

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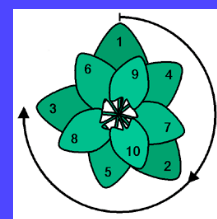

The golden angle
Approx. 137.5º

The sunflower petals

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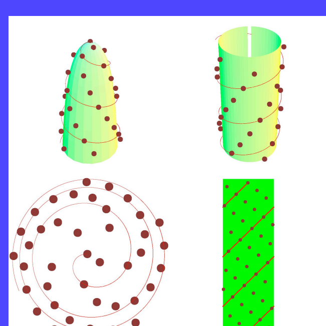
Phyllotaxis

- The arrangement of leaf buds (florets,…) on plant tissue
- The eye picks out obvious spirals called parastichies



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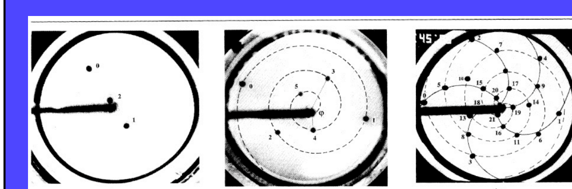

Douady, S. and Y. Couder (1992). "Phyllotaxis as a physical self-organized growth process." Physical Review Letters **68**(13): 2098-2101.

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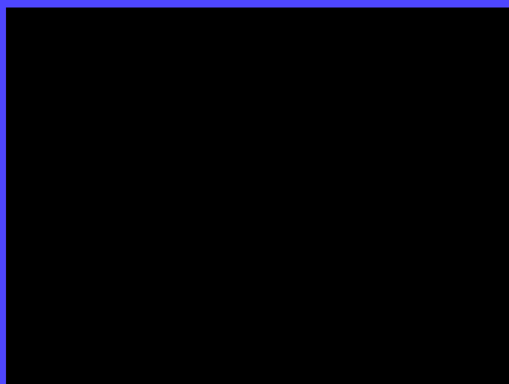
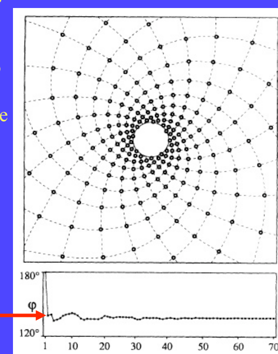


Magnetized drops of ferrofluid repelling each other, falling onto a horizontal dish filled with silicone oil.
They are also attracted by the magnetic field at the borders

137º.5



The case of language

Fibonacci structures found in:

- Syllables
- Prosody
- Syntactic structure
- Phase/non-phase alternations
- Discourse

Most frequent syllable structures

- In order of frequency, in languages the world over:
- (1) CV (and its stressed variant CVV),
- (2) CVC (and its stressed variant CVVC),
- (3) V and VC.
- There do not seem to be any syllable templates like CVVVC or VVC,
- The question is why only these basic patterns emerge, and with this (descending) frequency.

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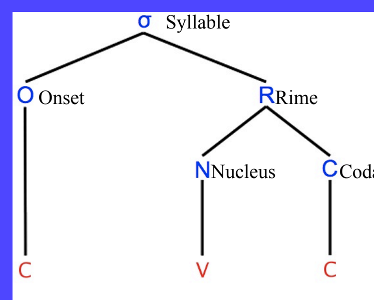
Tree structure of a CVC syllable



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Two factors "pulling"

- Syllables can emerge as properties of two factors:
- 'Pulling' the system in opposite directions:
- 'Repulsion' forces, due to ease of pronunciation, and minimal contrast, that generate F patterns more generally,
- and more specific 'Gluing' forces (rounding, assimilation etc.), that result in discrete units of various shapes.
- A syllable is a mini-max compromise, the 'max' aspect being determined by general F conditions, and the 'mini' one by the linguistic specificities that the local parameters dictate.
- An 'Equilibrium' should emerge and does

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Spaces are (-) and boundaries are (+)

(Juan Uriagereka 1998 and 2008)

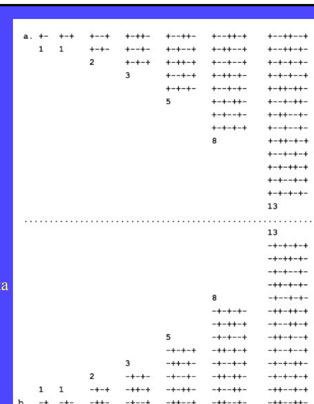

Fig. 1. F patterns emerging from the F game, for 2, 3, 4, 5, 6, 7 and 8 symbols.

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The F (Fibonacci) game.

- (i) Starting with either a + or a −,
- (ii) Go on to concatenate it to another + or a −,
- with one condition:
- (iii) Avoid combining identical symbols, unless they are adjacent to a different symbol.

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Linguistic conditions

- (i) *Nucleus constraint*: Look for a maximal space.
- Then,
- (ii) *Onset constraint*: Try to assign an onset boundary to that space.
- Then,
- (iii) *Coda constraint*: Try to assign a coda boundary to that space.

- This is an optimization algorithm, trying to make bounded spaces as large as possible,
- and as delimited as possible

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Spaces are (-) and boundaries are (+)

(Juan Uriagereka 1998 and 2008)

a.	+-	+-+	+--+	+-++-	+--++-	+--++-+	+--++--+
	1	1	+-+-	+--+-	+-+--+	+-++--+	+--++-+-
			2	+-+-+	+-++-+	+--+--+	+-+-+-+-
				3	+--+-+	+-++-+-	+-+-+--+
					+-+-+-	+--+-+-	+-++-++-
					5	+-+-++-	+--+-++-
						+-+--+-	+-++--+-
						+-+-+-+	+--+--+-
						8	+-++-+-+
							+--+-+-+
							+-+-++-+
							+-+--+-+
							+-+-+-+-
							13

							13
							-+-+-+-+
							-+-++-+-
							-+-+--+-
							-++-+-+-
						8	-+--+-+-
						-+-+-+-	-++-++-+
						-+-++-+	-+--++-+
					5	-+-+--+	-++-+--+
					-+-+-+	-++-+-+	-+--+--+
				3	-++-+-	-+--+-+	-+-+-++-
			2	-+-+-	-+--+-	-++-++-	-+-+-+-+
	1	1	-+-+	-++-+	-+-++-	-+--++-	-++--+-+
b.	-+	-+-	-++-	-+--+	-++--+	-++--+-	-++--++-

Fig. 1. F patterns emerging from the F game, for 2, 3, 4, 5, 6, 7 and 8 symbols.

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The phonological end-game

- First,
- the algorithm attempts to find maximal spaces (combinations of '−' elements);
- Next
- It attempts to delimit that maximal space in terms of an onset (if this is possible);
- Finally
- the algorithm tries to find a coda for the delimited spaces.
- In a few circumstances, the remaining space is a single '−' (not a maximal space), and in fact without either an onset or a coda - But this is a relatively rare circumstance.

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More terms of F

- Further combinations of successive (eight, nine, ten, etc.) symbols under these conditions
- Give more terms of the F series (twenty one, thirty four, etc.),
- but
- when the linguistic conditions are applied to these new objects, no more further combinations will arise.
- This is the entire set:
- a. + − b. + − − c. + − + d. + − −+
- e. − f. −+

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If - is a vowel + is a consonant

- **(a) grouping** (starting the game with a boundary) :
- CV 37 (times), CVC 21, CVV 11, CVVC 10, V 0, VC 0.
- **(b) grouping** (starting the game with a space):
- CV 37 (times), CVC 17, CVV 7, CVVC 8; V 19, VC 13.
- (We disregard secondary phonemes in consonant clusters)

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Historically unrelated languages

- The languages where these patterns obtain can be **unrelated**, historically or geographically
- So none of these generalizations seem attributable to the vagaries of history.
- Even more significantly, Perlmutter (1992) argued that syllabic distributions of the sort alluded to obtain **in signed languages too** (with no sound), where hand movements are the equivalent of open spaces, and hand positions of boundaries thereof.
- Confirmed recently (September 2008) by van der Kooij and Crasborn for Dutch Sign Language [*Lingua* 118 (2008) 1307–1327]

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Prosody

A metrical foot

- A metrical foot is a unit of prosody, determining the relation between beats and slacks in a given sentence,
- which **yields** a characte**ris**tic **rhyth**mic **pat**tern
- Such patterns are flexible within certain limits, with secondary beats emerging in sequences involving several slacks

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Idsardi 2008

a. 1 element, 2 possible parsings: (x), x
b. 2 elements, 5 possible parsings: (xx), (x)(x), (x)x, x(x), xx
c. 3 elements, 13 possible parsings: (xxx), (xx)(x), (xx)x, (x)(xx), x(xx), (x)(x)(x), (x)(x)x, (x)x(x), x(x)(x), (x)xx, x(x)x, xx(x), xxx

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The Fibonacci series

a. no initial foot: x | …, *n* elements left, therefore *f(n)* footings
b. 1–element foot: (x) | …, *n* elements left, therefore *f(n)* footings
c. 2–element foot: (xx) | …, *n–1* elements left, therefore *f(n–1)* footings
d. 3–element foot: (xxx) | …, *n–2* elements left, therefore *f(n–2)* footings
…
e. n–element foot: (x…x) | , 0 elements left, therefore *f(0)* = 1 footing

Generally then, $f(n+1) = f(n) + \sum_{i=0}^{n} f(i)$

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In essence:

- Syllables project
- Only some of these projections are heads
- Heads are grouped and such groups project again
- Groups can be right-headed or left-headed
- Their projections are again grouped (right or left, again)
- Only one element is left at the level of the maximal projection

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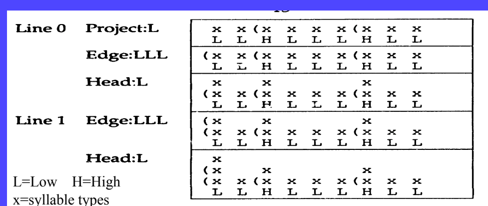
William J. Idsardi (MIT) 1992 *The Computation of Prosody*



The metrical grid module: 2 parameters of projection. Iterative constituent construction and Edge marking

The keys are:

- Simplest possible projections
- Optimal interweaving of rules and constraints
- Iterative parenthesis insertion
- Parametric binary choices between rightmost and leftmost elements.
- Insert left parenthesis when going right to left
- Insert right parenthesis when going left to right
- Until you reach the end.

"Fancy" by John Keats

- *Pléasure néver is at ho'me*
- (* * (* * (* * (* Gridline 0
- (* * (* * (Gridline 1
- (* *(Gridline 2
- * Gridline 3

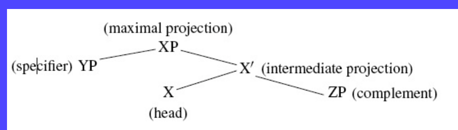
- *At a touch sweet pleasure melteth*
- (* * (* * (* * (* *(Gridline 0
- (* * (* * (Gridline 1
- (* *(Gridline 2
- * Gridline 3

Fabb, N. and M. Halle (2008). Meter in Poetry: A New Theory. Cambridge, UK, Cambridge University Press.

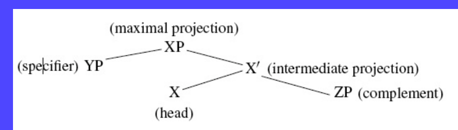
Fibonacci structures in syntax

Cedric Boeckx (Harvard)
Andrew Carnie (U Arizona)
Jordi Fortuny (U Groningen)
Angel Gallego (U Barcelona)
William Idsardi (U Mayland)
David Medeiros (U Arizona)
Alona Soschen (MIT)
Juan Uriagereka (U Maryland)

The basic "molecule of language"



The basic "molecule of language"

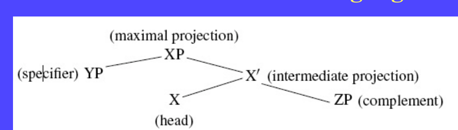


This "molecule" (X-bar structure) can, **as a whole**, be itself a ZP
and so on, indefinitely

Notice

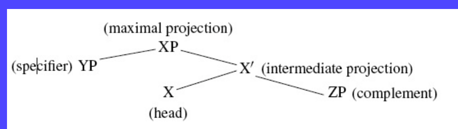
- From every node a maximum of two branches depart
- **Binary branching** is one of the best established facts about language
- Two is the minimum number for the operation Merge
- So it's also the maximum

The basic "molecule of language"



1 molecule,
1 projection (X'), 2 dependents (YP, ZP),
3 terminals (YP, X, ZP),
5 total categories (XP, YP, X, Z, ZP).

The basic "molecule of language"



there is no natural grouping of four or six elements in this structure
and of course 4 and 6 are not F-numbers.

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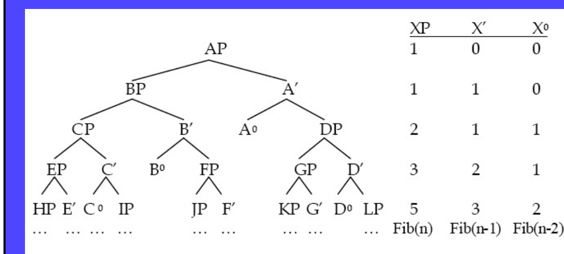
David Medeiros, 2008



Maximally balanced syntactic tree

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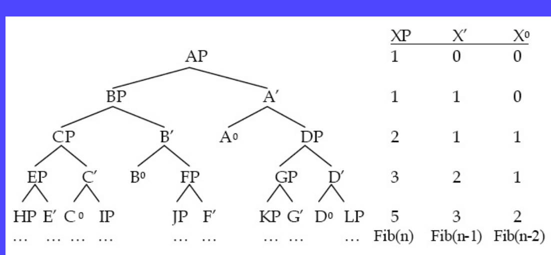
David Medeiros, 2008



Our "molecule" is reproduced everywhere

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Forcing F-structures by embedding

- F terminal string lengths are the first to force deeper phrasal embeddings in terms of the basic molecule.
- The issue is to determine the **least** embedded 'tree' possible for given terminal elements,
- respecting the basic (e.g., binary branching) conditions.

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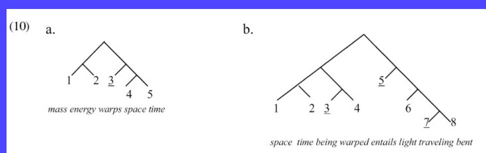

optimal tree representations for five and eight terminals, demanding three and four levels of embedding, respectively

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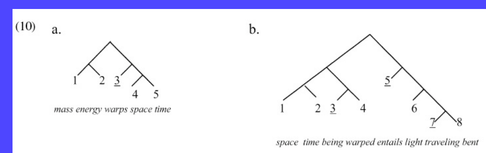
Four terminals (a number not in the F sequence) does not force *a third level of embedding*.
The next number of terminals that forces a further level of embedding under these conditions is five (a number in the F sequence). The same happens with eight, thirteen, twenty one (etc.) terminal elements.



optimal tree representations for five and eight terminals, demanding three and four levels of embedding, respectively

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Central property

- *The* central property of an F pattern - as central as its overall simplicity - is that
- as it grows it remains the same F pattern, thus it is *self-similar.*

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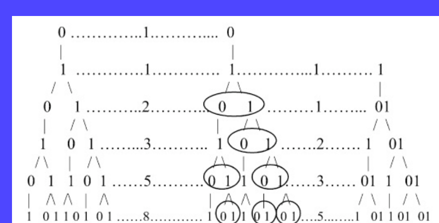
A simple rewrite system like 0→1, 1→0 1, when applying maximally at each derivational line in the computation (all rewritable symbols rewrite), generates an F pattern:



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One level higher: Cycles and Phases

- The syntactic derivations that generate a complex sentence have specific and mandatory points of closure.
- These partially structured chunks are 'sent' to the interfaces (PF and LF) before the sentence is completed
- and once sent, they **become impenetrable** to further computations.
- Chomsky suggests that systemic phases, aside from their various phonetic and semantic consequences, are necessary to make its computations workable.

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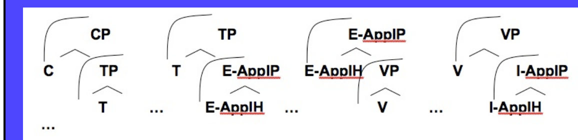
PHASE PARALLELISM

A. Soschen (2007, 2008)

Phases are primarily characterized by their capacity to project extra Spec positions, to ensure continuation of movement.



ECM constructions ('*Mary wants John to sing*') are absent in e.g. Polish, Russian, Italian, Spanish. The reason: <u>Phasal TP</u>. Head T_{inf} fails to assign case to NP in Spec,T_{inf}P due to the properties of T_{inf}, and derivation crashes.
The same languages lack Optional Infinitival Stage (*Mary like John*, TP omission, see Wexler 1998). Evidently, *min*-phases are preserved at an early stage of language development.

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Forces "pulling" in opposite directions

- Building up the whole hierarchical tree
- Versus
- Linearization

- The derivation proceeding right to left and inside-out
- Parsing proceeding left to right

- Another 'minimax' equilibrium?

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The Phase / not-Phase rhythm

- $[_P [_N [_P [_N [_P [_N \ldots]]]]]]$
- The idea is that successive categories in the syntactic skeleton (whatever they turn out to be: TP, CP and so on)
- stand in a phase/not-phase 'rhythm' with regard to one another.
- Possibly, in languages that admit more projected material

- $[_P [_N [_N \ldots [_P [_N \ldots [_P [_N [_N \ldots]]]]]]]]$

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Phasal conditions (Uriagereka)

- Three more phasal conditions can be argued for, when right edges are studied,
- + indicates a phase edge, - a phase core
- a. +−
- b. +−−
- c. +−+
- d. +−−+
- e. −
- f. −+
- In order of frequency, in the world languages
- This, is of course identical to the series of syllabic patterns that we sketched above.

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Optimal structures in language

- Syllable structure in all languages
- Tonic accent assignment in all languages
- Syntactic trees
- Internal units in sentences (phases)
- Some discourse structures

- Balancing two opposing “forces”
- Two orders of computations “in the mind”

- Glue together versus distinguish
- Produce versus parse

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Conclusion

- Optimality regardless of any specific “function” indicates physico-chemical-formal factors
- The cases in language could be explicable by
- Exaptation upwards
- Percolation downwards
- Possibly to be one day solved by means of neuronal computations
- They are inexplicable in terms of communicability requirement
- And in terms of neo-Darwinian adaptationism
- Just like other instances of the laws of form in biology.

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