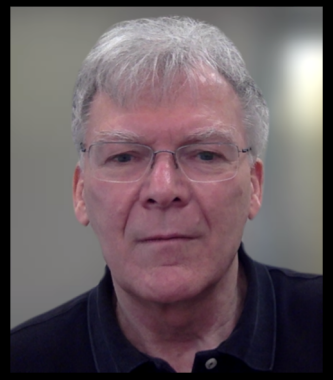
Abstract Forms & Tangible Biology – palanquins, princes, and a LEGO hypothesis



Douglas Brash
Yale School of Medicine

Asked to address

Are there abstract Forms and mathematical objects in biology?
How can they be causal?

Overarching Question

Are there laws for biology? Where do they come from? What do they operate on?

Outline

I. Mathematical objects in science

II. Biological forms & emulating the external world [Kinematics / Operands]

III. How do biological forms get created?

IV. Laws: giving mathematical objects causal power [Dynamics / Operators]

V. How to evolve causal forms: a LEGO hypothesis

I. Mathematical objects in science

1. Eerie relationships appear in abstract math & real world physics

Math: Euler's Identity

$$e^{i\pi} + 1 = 0$$

Physics: Fine structure constant
(gap between spectral lines
of the hydrogen atom)

$$\alpha = \frac{e^2}{4\pi\epsilon_0\hbar c}$$

I. Mathematical objects in science

2. Why physics is abstract and mathematical

COMMUNICATIONS ON PURE AND APPLIED MATHEMATICS, VOL. XIII, 001–14 (1960)

The Unreasonable Effectiveness of Mathematics in the Natural Sciences

Richard Courant Lecture in Mathematical Sciences delivered at New York University, May 11, 1959

EUGENE P. WIGNER
Princeton University

Mathematicians:
"The concepts outside those contained in the [theorem's] axioms are defined with a view of permitting ingenious logical operations which appeal to our aesthetic sense, both as operations and in their results of great generality and simplicity."

Physicists:
Find mathematics that resembles the physics, though it often applies beyond the initial physical phenomena.
"Because we do not understand the reasons of [the theory's] usefulness, we cannot know whether a theory formulated in terms of mathematical concepts is unique."

I. Mathematical objects in science

2. Why physics is abstract and mathematical

Max Born

SYMBOL AND REALITY

[First published in *Universitas,* Vol. 7, No. 4, pp. 337–353 (1965).]

1. Why is Science Abstract and Mathematical?

If somebody who is no physicist, chemist or astronomer, would glance through any paper or book on these sciences, he will be struck by the amount of mathematical and other symbols and the scarcity of descriptions of natural phenomena.

- Math depicts patterns, independent of particular instantiations.
  - MB?: These patterns arise from definitions + axioms
  - DB: Patterns in physics arise from constraints that correspond to axioms in math.

- Objective observations *must* be abstract symbols.
  - My green might be my brother's blue. So the only observations that can be objective [agreed upon by observers] are *comparisons* of physical states. E.g., green object becoming blue.
  - The result of a comparison must be a symbol, i.e., abstract.

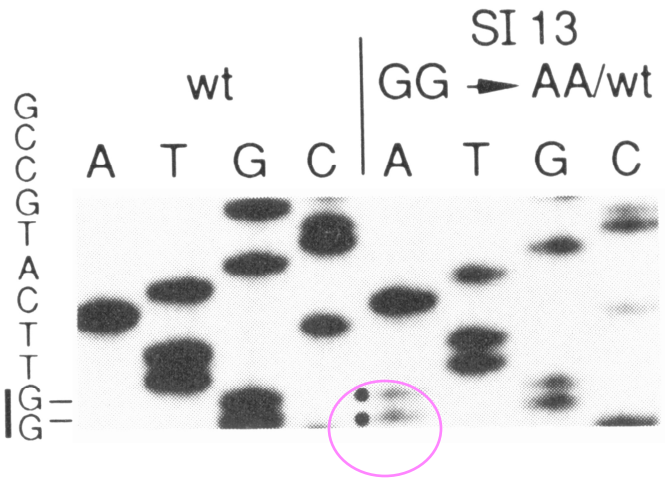
I. Mathematical objects in science

2. Why ~~physics~~ the world is abstract and mathematical

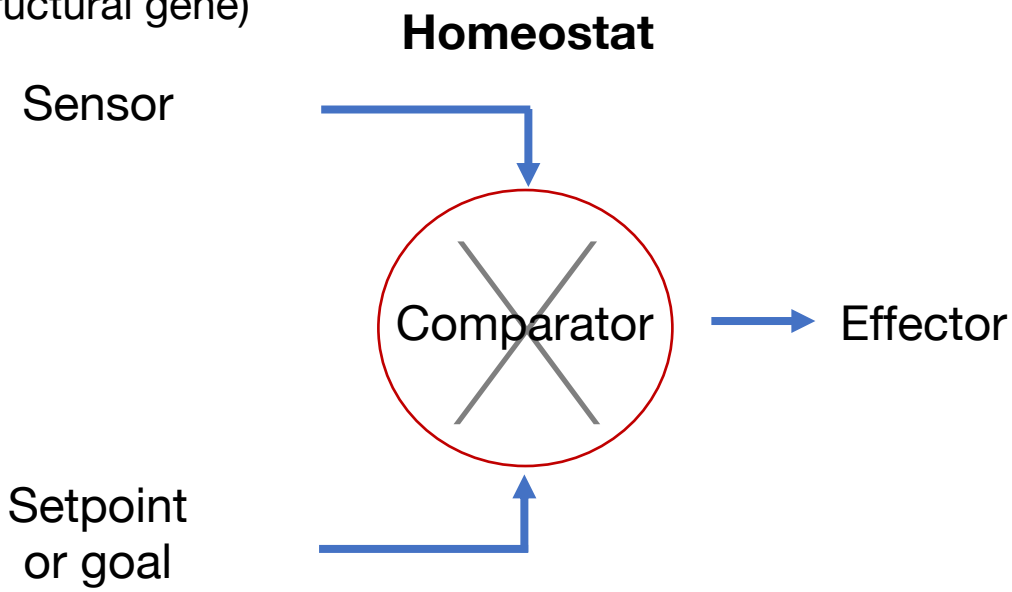
Comparisons are pervasive in science

To show "DNA mutation Q leads to altered protein function":

band on DNA sequencing gel = spot wrt surround
base identity = lane wrt base-specific chemical rxn
DNA sequence position = band location wrt gel start point
mutation = DNA sequence wrt normal sequence
regulatory vs structural location = DNA sequence wrt amino acid codons
DNA sequence motif = sequence wrt known motifs (e.g. TATA box in promoter)
amino acid change = DNA sequence wrt amino acid code (if structural gene)
functional impact = mutant protein behavior wrt normal protein



Homo sapiens didn't evolve from chimpanzees; we evolved from homeostats – DB



I. Mathematical objects in science

2. Why ~~physics~~ the world is abstract and mathematical

WS McCulloch 1947

"How We Know Universals." Our idea is basically simple and completely general, because any object, or universal, is an invariant under some groups of transformations and, consequently, the net need only compute a sufficient number of averages a_i, each an N^{th} of the sum for all transforms T belonging to the group G, of the value assigned by the corresponding functional f_i, to every transform T, as a figure of excitation ϕ in the space and time of some mosaic of neurons. That is,

$$a_i = \frac{1}{N} \sum_{\substack{\text{all} \\ T \epsilon G}} f_i[T\phi]$$

WS McCulloch, Embodiments of Mind

I. Mathematical objects in science

3. Plato's Forms (as I understand them) are not mathematical objects

Plato's timeless forms or abstract patterns

- Are just there.
- No relations or laws connecting two Forms.
  - circle
  - chair (so evidently a Form can have internal relations between its parts)
  - the good
  - There is no physics of Chair

Mathematical objects

- Are abstract operands that also have operators to act on them.
  - Euler's identity, more explicitly:

$$e^{(i \cdot \pi)} + 1 = 0$$

Plato's Forms

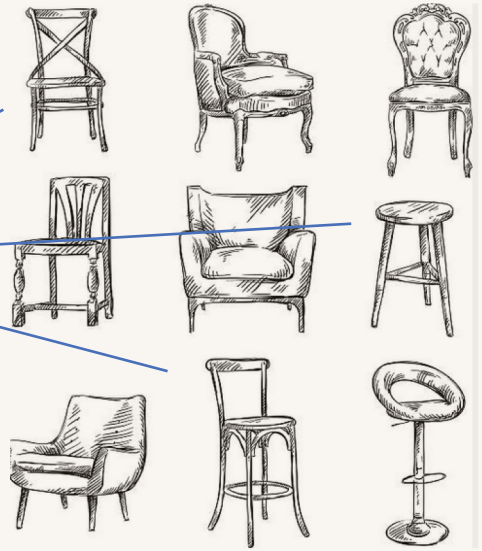
Justice

there is no physics of Chair

Goodness

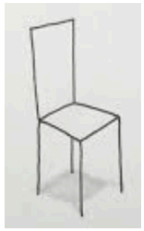
Instantiations

Platonish Representation



Plato's Forms

Justice

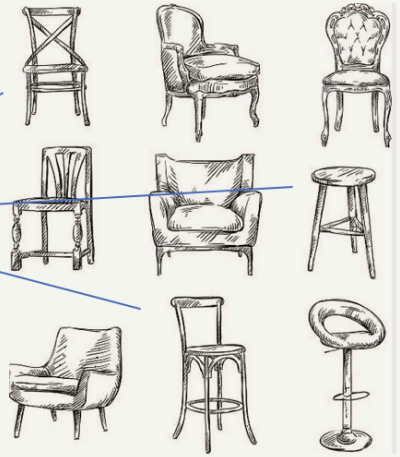


there is no physics of Chair

Goodness

Instantiations

Platonish Representation



Huh Cheung Wang Isola
Alternate Observations/Decompositions

AI #1 {P,Q,R} ...

AI #2 {X,Y,Z} ...

these deduce the real-world instantiations; they evidently also capture operations

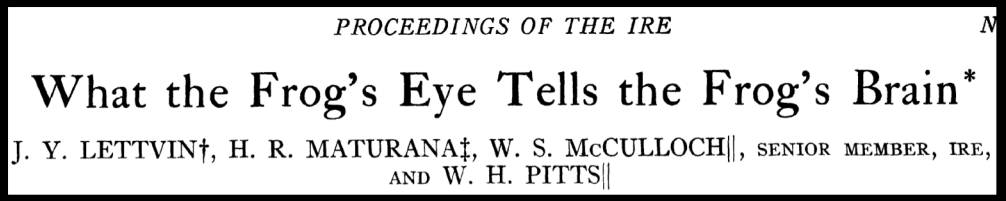
Platonish Theorem:

Find a vector embedding in which similarity equals pointwise mutual information.

A generalization of "neurons that fire together, wire together"?

Dislodging us from Legacy Worldviews

"Forms are universal"

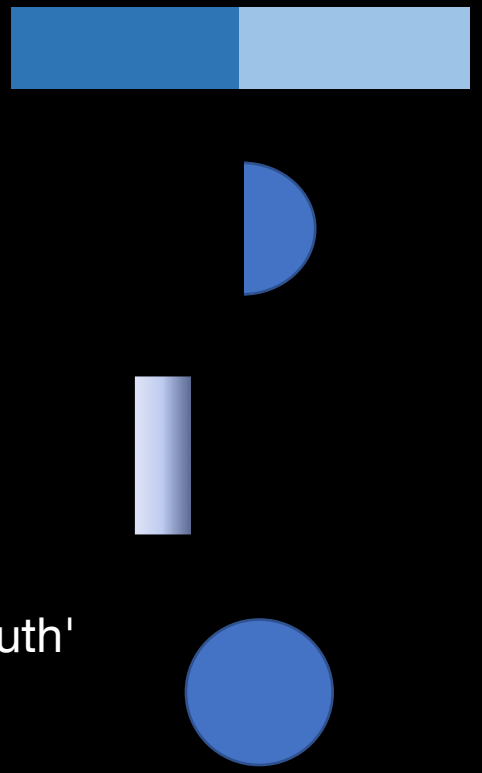


PROCEEDINGS OF THE IRE N

What the Frog's Eye Tells the Frog's Brain*

J. Y. LETTVIN†, H. R. MATURANA‡, W. S. McCULLOCH‖, SENIOR MEMBER, IRE, AND W. H. PITTS‖

Conclude:
Cellular basis of Kant's categories
Are a basis set, axes, or alphabet, rather than 'truth'
Dimensionality-reduced mapping from 'truth'
Unlike 'truth', differs between species
Human Forms are not privileged basis vectors or "truth"
Even Plato's abstract Forms are anthropocentric



contrast

unmyelinated

convexity

moving edge

myelinated

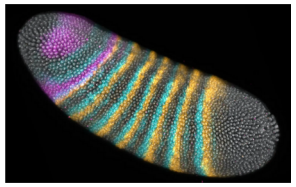
dimming

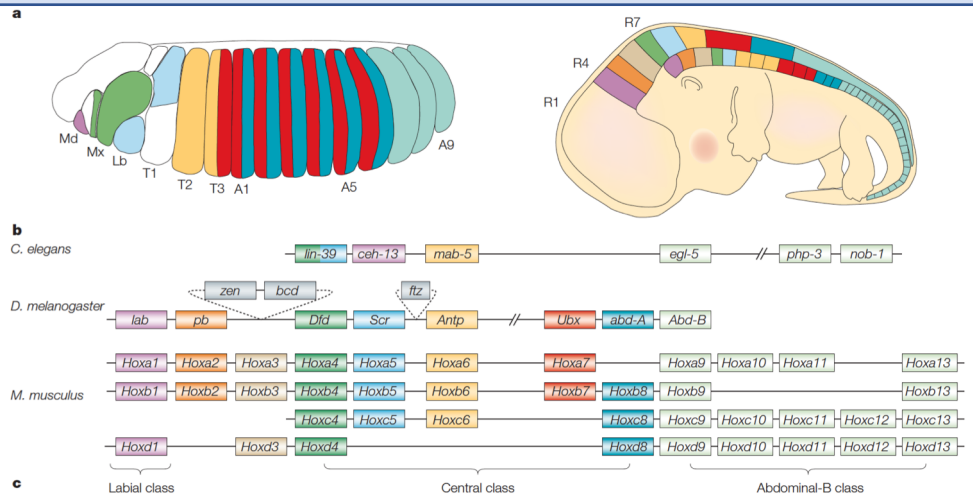
Lettvin, Maturana, et al. Proc. Inst. Radio Engr. 47:1940, 1959

II. Biological forms & emulating the external world [Kinematics]

1. Biology contains abstract forms

Tangible:
D'Arcy Thompson
Drosophila body plan

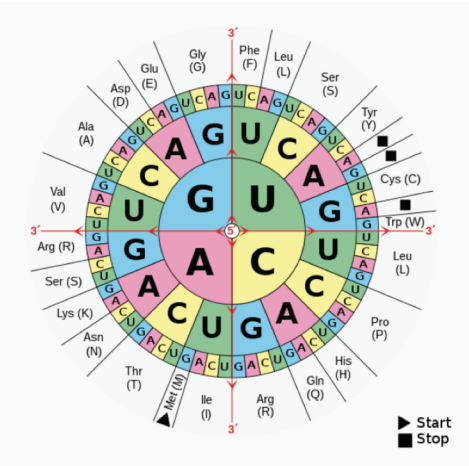




Homeobox genes

Abstract:

Genetic code



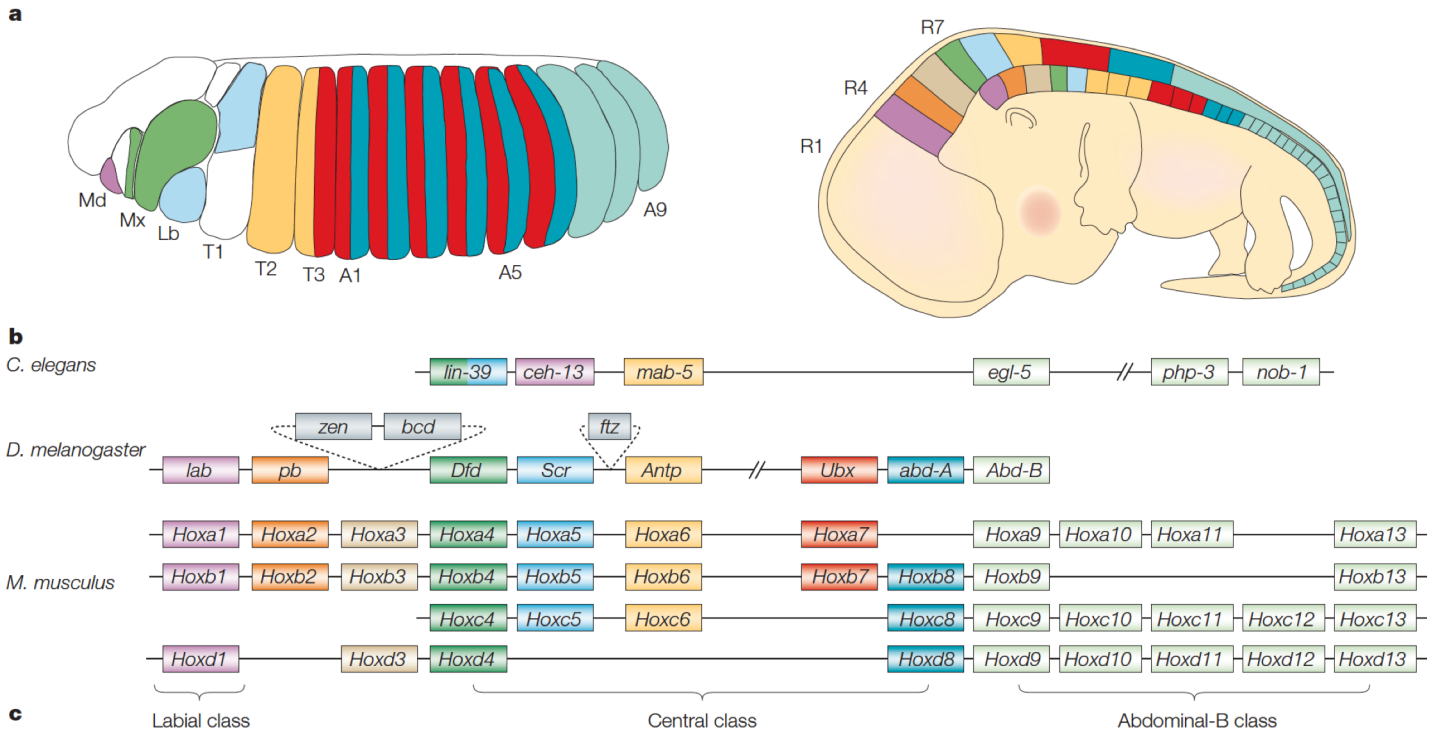
Efficiency of molecular machines

DNA binding proteins, visual pigments, & ecosystems operate at 69% efficiency – the thermodynamic limit for bistate machines, machines that have 2 states that must be distinguishable.

Schneider, TD. Nucleic Acids Res. 38:5995, 2010

II. Biological forms & emulating the external world [Kinematics]

2. Effector representations are exotopic



Homeobox genes act along the developing segmented embryo in the same sequence they occupy on the chromosome.

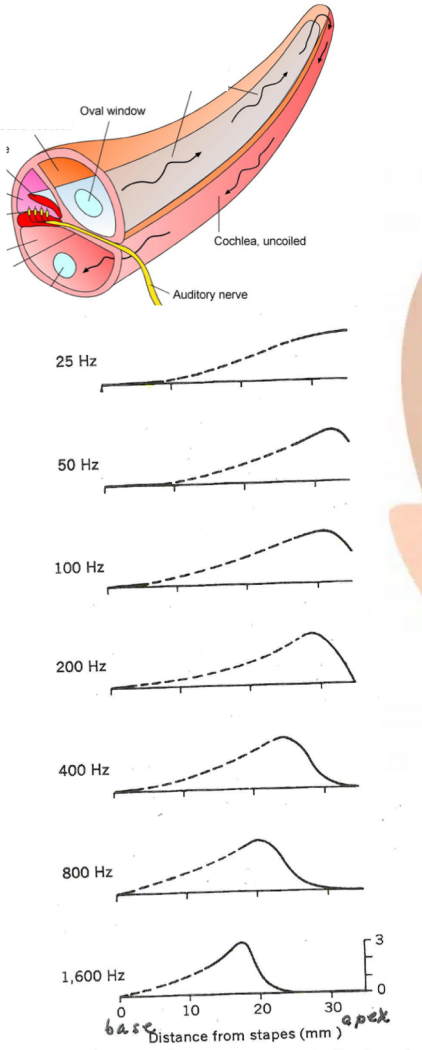
Pearson, Lemons, & McGinnis. Nature Rev. 6:893, 2005

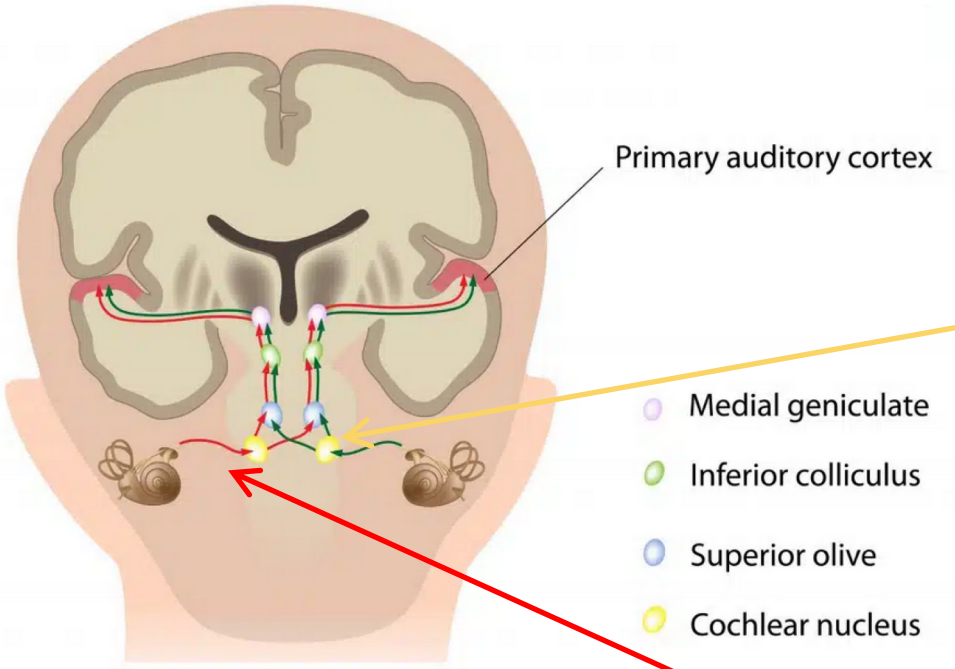
macro	tangible
micro	abstract

But: Is the gene arrangement an internal representation of the external form or a mechanical cause of it?

II. Biological forms & emulating the external world [Kinematics]

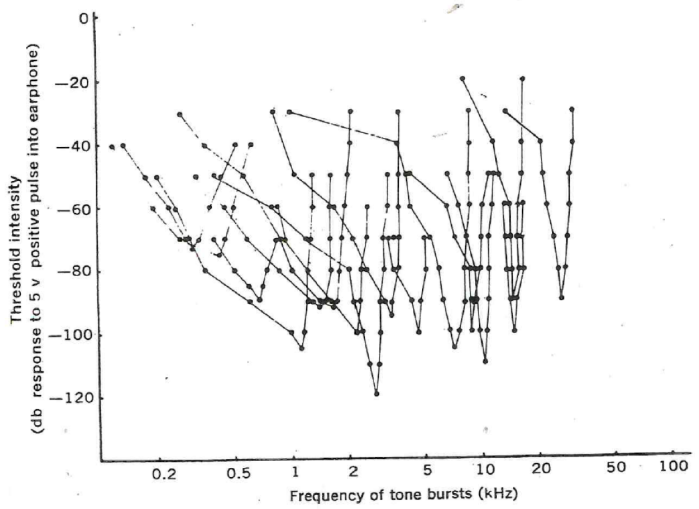
3. Sensory representations – sound is represented tonotopically





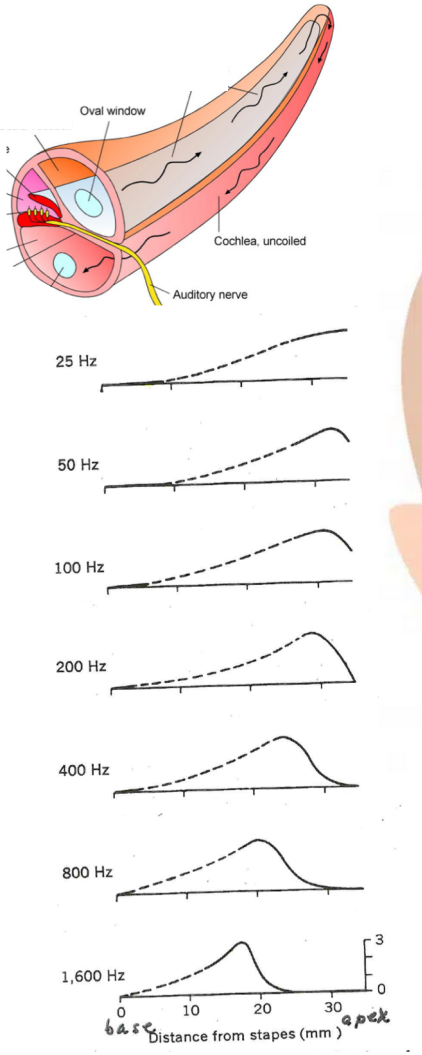
The constituent fibers then bifurcate, one branch ending in the *dorsal cochlear nucleus* and the other branch in the *ventral cochlear nucleus*. The cochlear nuclei lie on the surface of the upper end of the medulla adjacent to the root of the inferior cerebellar peduncle

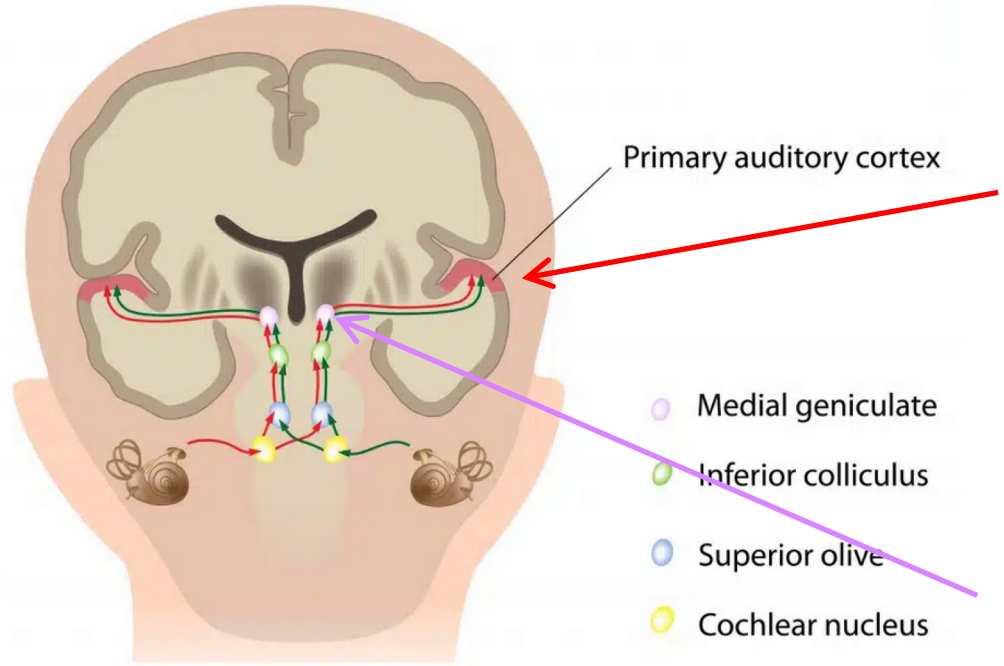
A tonotopic pattern of axonal endings (from base to apex of the cochlea) has been demonstrated in both nuclei

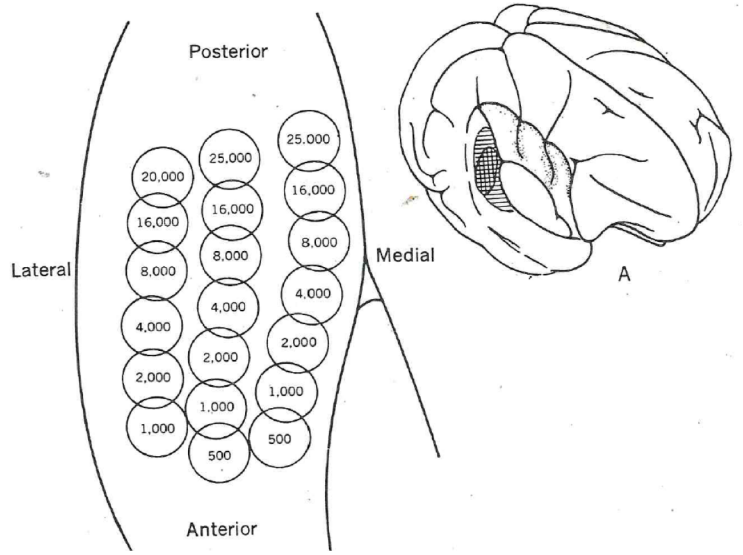


II. Biological forms & emulating the external world [Kinematics]

3. Sensory representations – sound is represented tonotopically



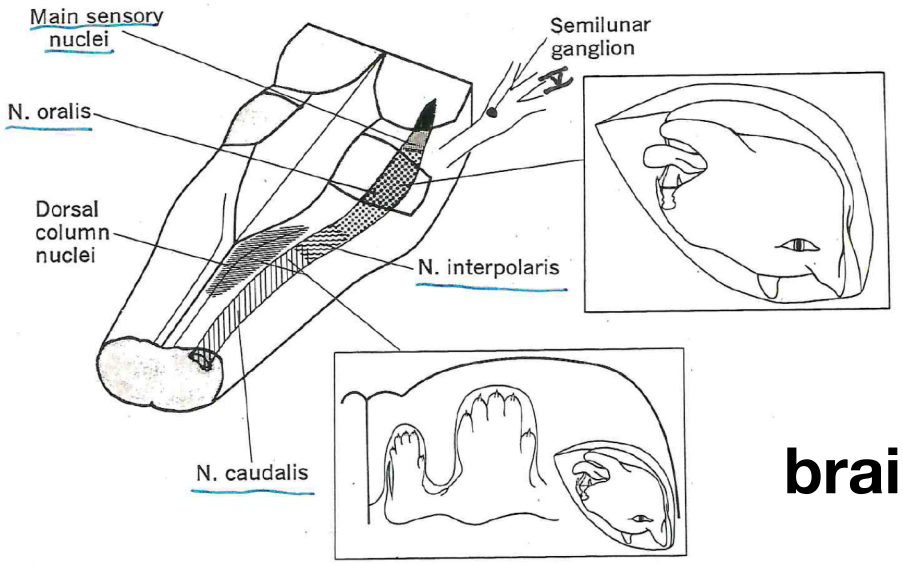




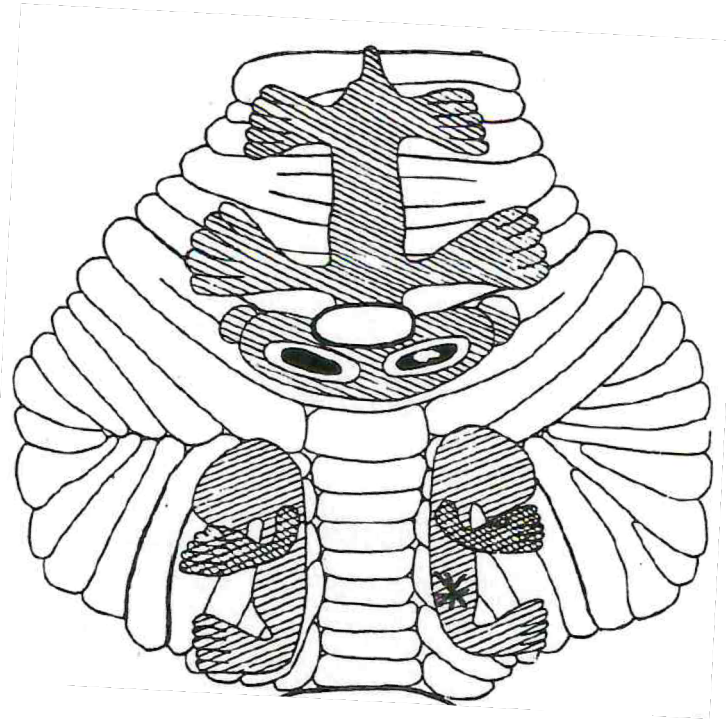
The termination of axons in the medial geniculate nucleus of experimental animals is such as to produce a spiral pattern for tones corresponding to the spiral of the cochlea

II. Biological forms & emulating the external world [Kinematics]

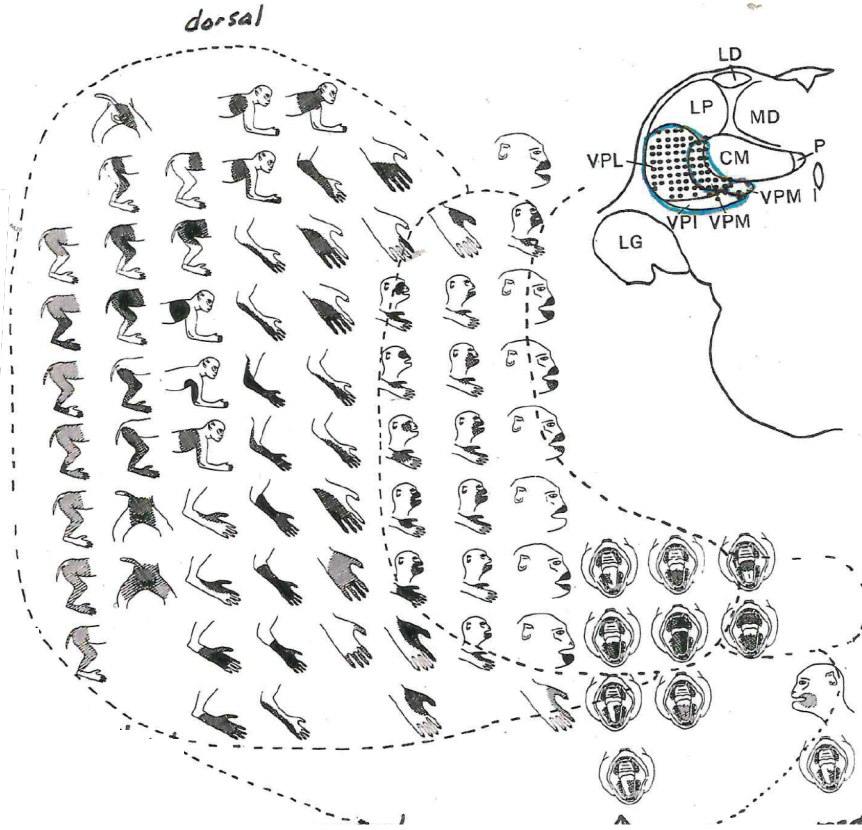
3. Sensory representations – touch is represented somatotopically



brainstem



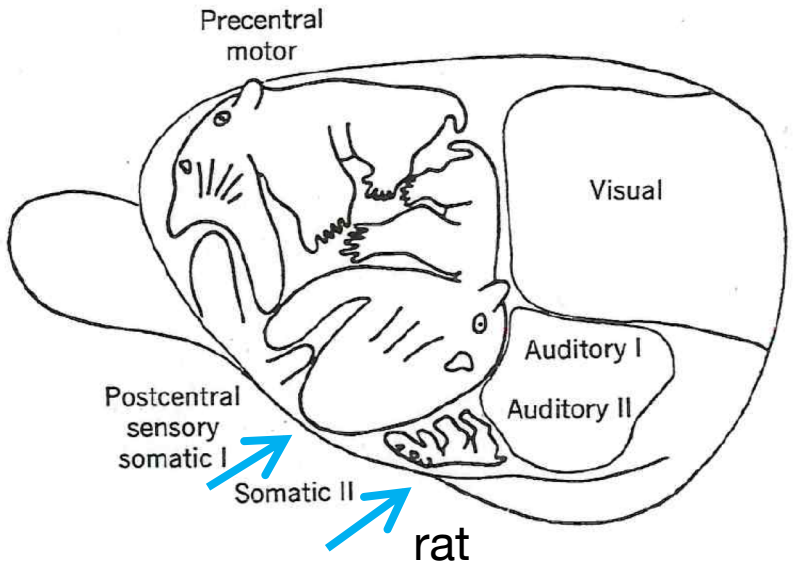
cerebellum



thalamus

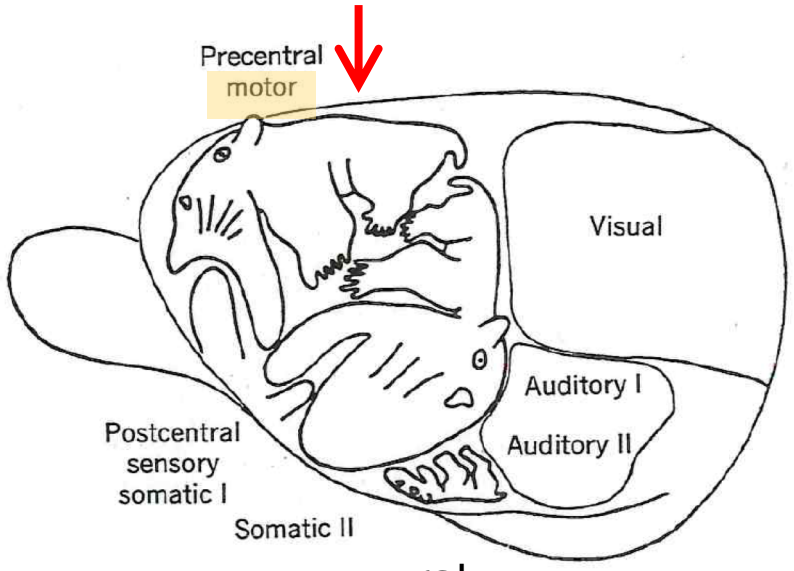
II. Biological forms & emulating the external world [Kinematics]

3. Sensory representations – touch is represented somatotopically

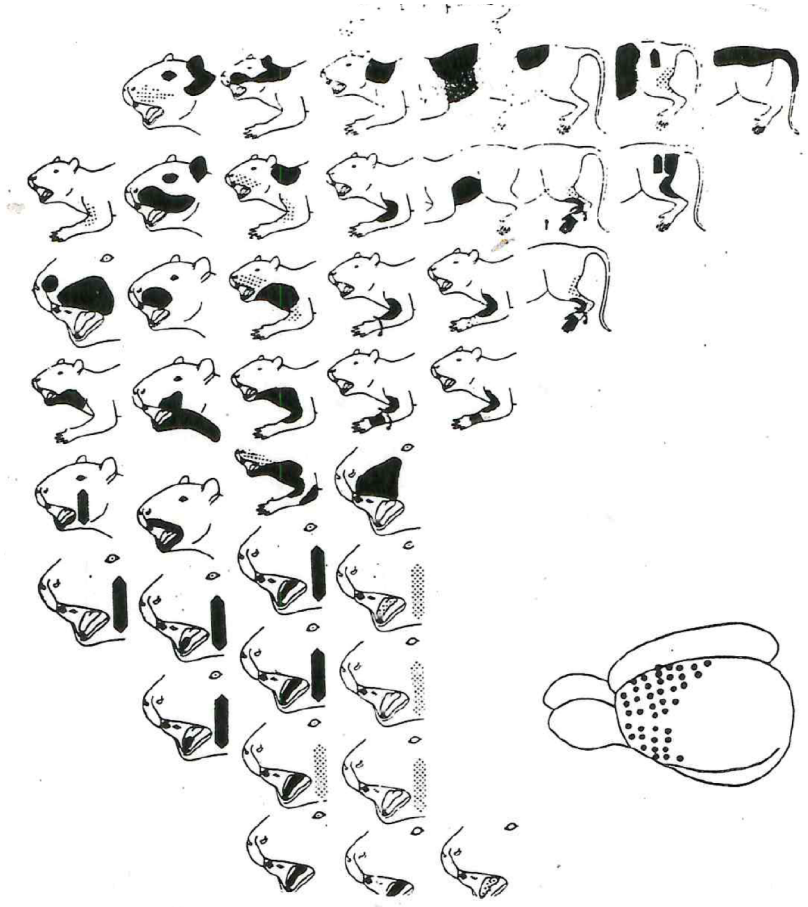


II. Biological forms & emulating the external world [Kinematics]

4. Effector representations – motor function is also represented somatotopically



rat



What's the payoff for a contiguous map?

Avoids: Two representations in same place; 1 rep in two places

Ensures: Know when representation is complete,
Operators operate on adjacent operands.

- If these functional properties are the *drivers* of the Form's structure,
is the anatomical Form a map or just a side effect of embryology?

II. Biological forms & emulating the external world [Kinematics]

5. Language uses an exotopic form

If we posit:

- Cognitive symbols are grounded symbols resembling their referent (like a pedestrian crossing sign), not arbitrary symbols (like 0 & 1), per Harnad 1990 discussed later.
- Language symbols are grounded by imitating the external world as humans see it (19th century linguistics).
- Humans see the world as made of Entities with relations between them (atoms joined by bonds, chair parts aligned by bolts). This is a triadic structure, not function-argument.
- Language puts grounded symbols into triadic structures.

Then:

- Natural language has a simple structure, parsable w/ an 8 MB program.

II. Biological forms & emulating the external world [Kinematics]

Language structure is triadic: entity-relation-entity

Expressing English as entities and relations reveals that system-component relations are unspoken:

Word string	'Experts'	'predict'	'improvements'		
Icon/meaning	EXPERTS	PREDICT	IMPROVEMENTS		
Notation	(Experts)	predict	(improvements)		
Word string	'the'		'green'		'grassland'
Icon/meaning	KNOWN SET	composed of	GREEN	component of	GRASSLAND
Notation	(the)	⌈	(green)	⌉	(grassland)
Word string	'person'		'who'	'threw'	'it'
Icon/meaning	PERSON	component of	WHO	THREW	KNOWN ITEM
Notation	(person)	⌉	(who)	threw	(it)

This is data compression!

II. Biological forms & emulating the external world [Kinematics]

Omitted adverbs:	(He) met (me) *at* (there).
	(They) raised (prices) *by* (8%).
At higher levels of organization:	
adjectival complement	(He) found <(her)⌈ (asleep)>
indirect object	(Coolidge) gave [(Mama) ⌈ <(this) ⌈ (dress)>]
clausal complement	<(the) ⌈ (fact)> ⌈ { (the) ⌈ (young) ⌉ (girl) was (courageous) }
Omitted Entities:	
gerund (“cooking”)	(something) cooks (something)
participle (“had cooked”)	(something) cooked (something)
infinitive	(Casey) wants { (PRO) to.infinitive [(PRO) throw <(the) ⌈(ball)>] }.
intransitive	(He) slept.intrans (himself).
object relative	(Cats) ⌉ {(that) ⌉ [<(my) ⌈ (dog)> chases ( )]} are
Omitted phrases:	<(The)⌈(horse)> ⌉ { (that) was [(raced) past <(the)⌈(barn)>] } fell.intrans (itself).

II. Biological forms & emulating the external world [Kinematics]

The pattern prior to data compression is regular

(necessities) of (life)

(necessities) were (free)

(necessities) of (life) were (free)

(The) ⌈ (person) ⌉ (who) threw (the) ⌈ (ball) is (athletic) .

(The) ⌈ (Kremlin) are (studying) ⌈ (the) ⌈ (President) 's ⌈ (letter) .

II. Biological forms & emulating the external world [Kinematics]

Language processing is guided by a template exogenous to the sentence:

E	rel	E	rel	E	rel	E	rel	E	rel
(He)	saw.vb	(the)	⌜	(saw.E)	.				
(He)	saw.vb	(the)	⌜	(saw.E)		(Clive)	saw.vb	( )	.
(He)	saw.vb	(the)	⌜	(saw.E)	⌝	(Clive)	saw.vb	( )	.

- Simplifies word disambiguation & data decompression.
- Word disambiguation & gap insertion cannot reside in the word or the dictionary.
  The sequencing track *must* be exogenous to the sentence: a neural template.
- The sequencing track is the backbone.

We'll return to this when we discuss operations.

III. How do biological forms get created?

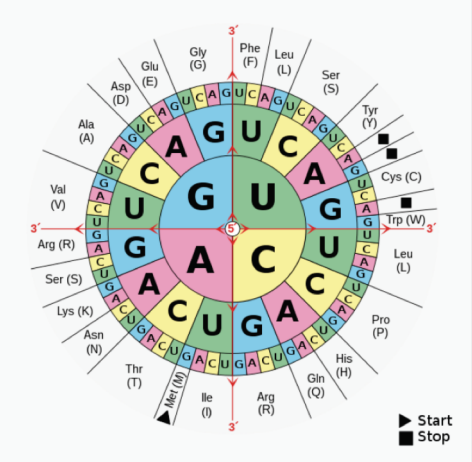
1. Some Forms are inherited.
    - *Hox* gene order
    - *Drosophila* embryo segmentation
    - Tonotopic representation of sound
        - cochlea dictated by anatomy; brain nuclei dictated by neuronal mechanics or constructed?

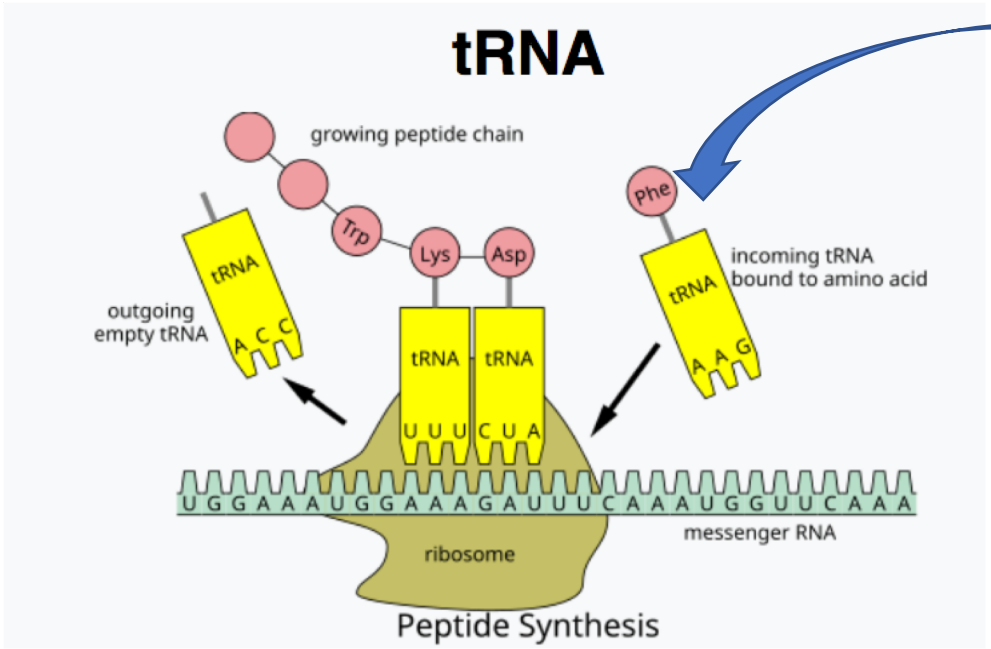
2. Some Forms are probably constructed.
    - Somatotopic representation of touch
    - Severed optic nerve neurons regrow to correct location (Sperry)
    - "Fire together, wire together"?
    - Generalization: Cells performing processes that occur together differentiate together?

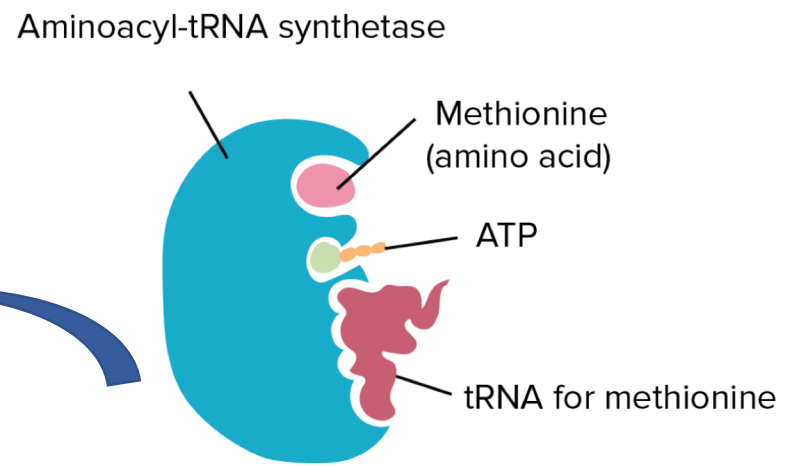
3. Some human Forms evolved from others.
    - Language's hierarchical structure has been proposed to derive from herarchical throwing movements.

III. How do biological forms get created?

4. Where does biology keep the genetic code?







tangible

abstract*
at micro

* "A molecular biologist is someone who thinks that adenine is A."

III. How do biological forms get created?

5. There are restrictions on bridging the external world to internal representations

A. Harnad elements of cognition

Cognition manipulates internal symbols in order to process the external world.

Arbitrary symbols, as in 0 & 1 or Chomskian linguistics, lack the information needed for cognition:

- Discrimination, by comparing two symbols for differences.
- Recognition, categorization, and generalization, by comparing symbols for similarities.

Grounded symbols – icons, like a pedestrian crossing sign – have a physical correspondence to their referent. This allows computations on their parts, mimicking behaviors of the external world.

B. Ashby internal models & Markov blankets

If a tangible 'thing' is surviving by regulating its tangible external world, it must contain an abstract model of that external world. The simplest accurate model is a map.

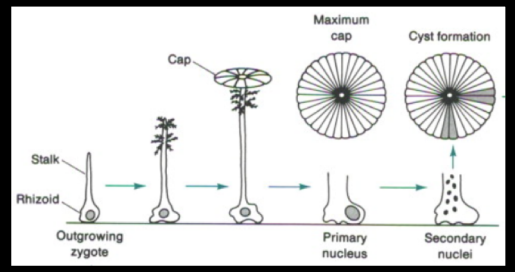
If all information connecting external and internal domains partitions into sensory transducer states affecting the internal state but not v.v. and effector transducer states affecting the external world but not v.v., then the internal will model external behavioral probabilities not current status.

Harnad, Physica D 42:335,1990
Conant & Ashby, Int. J. Systems Sci. 1:89,1970 (but see johncarlosbaez.wordpress.com/2016/01/27/the-good-regulator-theorem/)
Fields et al. Neurosci Consc 2025(1) niaf009

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

Two Kinds of Laws

1. Prescriptions. Organism builds structure (or activity) following a map.



Single-cell *Acetabularia*

abstract Forms nudge us toward this one.

2. Invariants. Organism structure (or activity) satisfies a criterion.

Usually "c is constant even when a & b change".

x, t change but momentum is constant

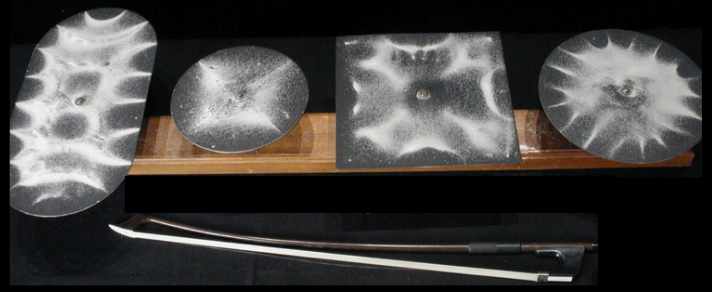
PV = nRT

abstract Math nudges us toward this one.

Dislodging us from Legacy Worldviews

"Patterns come from maps or goals"

Chladni plate



Conclude:
Newton's Laws push the salt grains at the micro level but they don't cause the pattern at the macro level.
The pattern comes from constraints at the macro level (i.e. correlated across the plate; plate edges, vibration frequency).
Micro motion is from Newton, but macro direction/pattern is from constraints.

Micro non-directional motion + Macro directionality = Carnot heat engine (fire + piston)

>1 micro input & >1 macro output constraint, so: "Chladni heat engine"

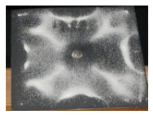
Constraints: Schrödinger ← Hamiltonians ← Lagrange w LaGrangian multipliers ← D'Alembert's Principle

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

1. Two solved examples:

Chladni plate:

pattern 1



pattern 2

abstract macrotype

particles & constraints 1 → particles & constraints 2

tangible microtype

Noether's Theorem: Conservation laws (momentum, energy) result from symmetries in translation or rotation through space or time (no boulders, whirlpools, or tunnels).

law abstract

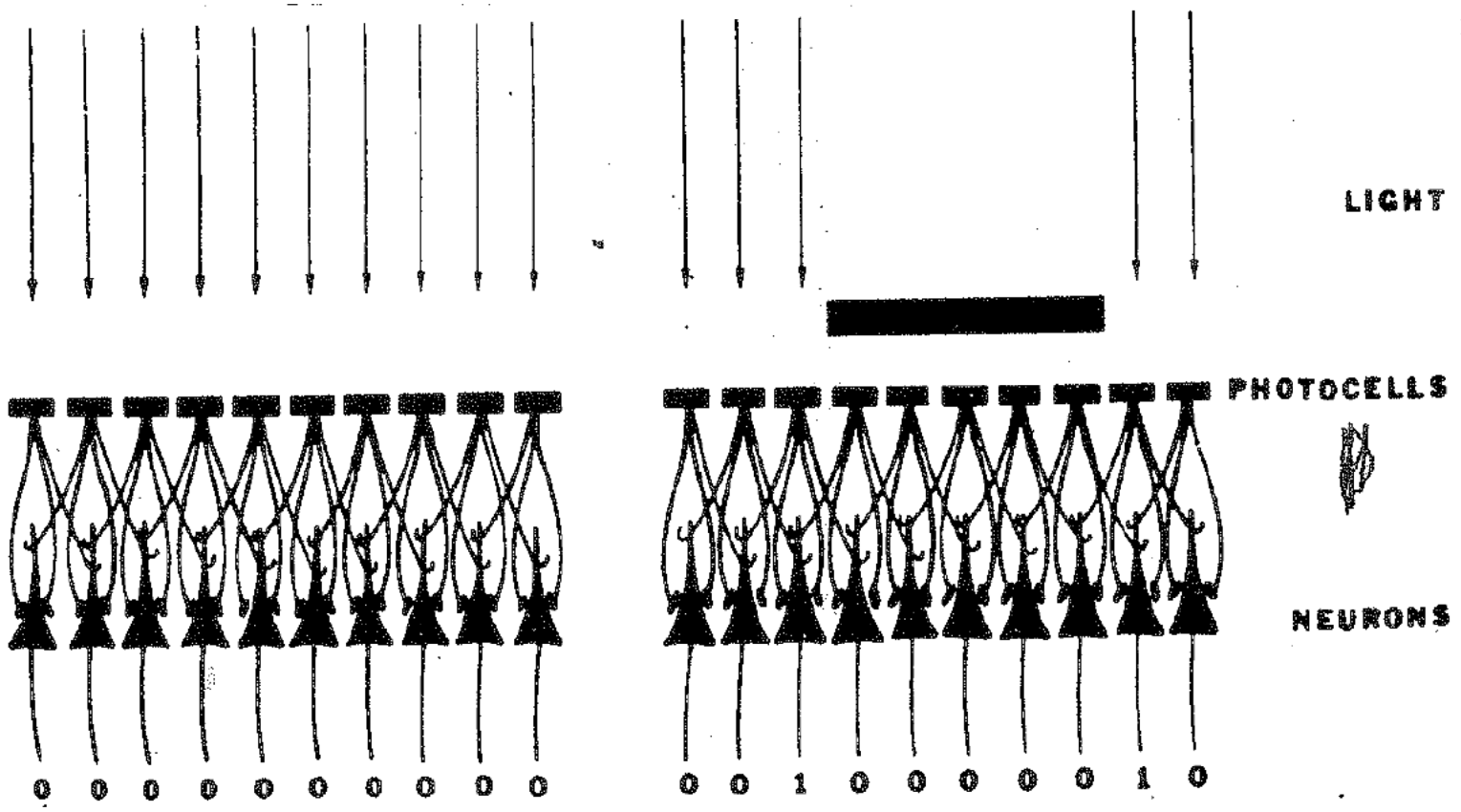
↑

particle & symmetry tangible

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

2. Causality from algorithms, not maps

Lateral inhibition algorithm: a lit photoreceptor activates its neuron & inhibit its neighbors



IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

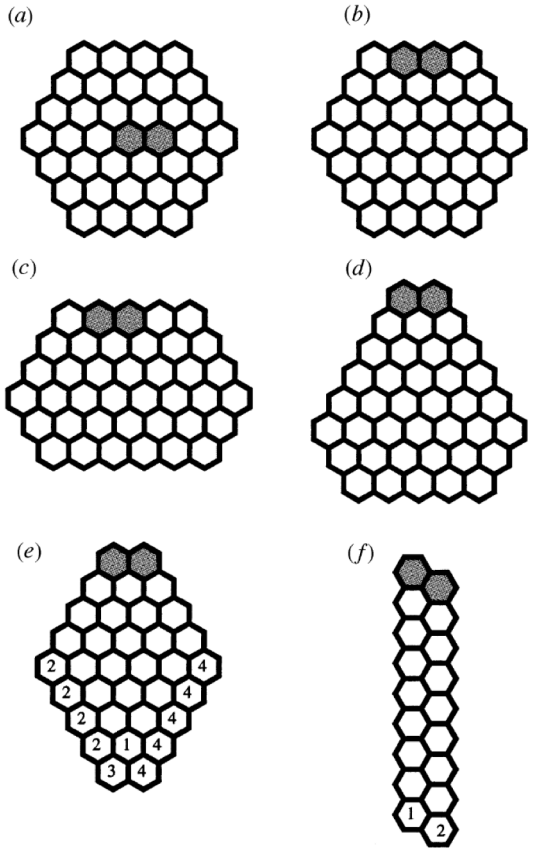
3. Causality from algorithms, not maps

Wasp nests

algorithm: if you see pattern P, spit here; if you see pattern Q, spit there

"Stigmergy" – a 3rd kind of Law, micro motion + external constraints

Resembles Chladni plate. Can imagine embryos doing this.



Dark = first cells. (a) *P. dominulus*. (b) P. *exclamans*. (c) *P. fuscatus*. (d) *P. annularis*, (e) *P. canadensis*, (f) *P. goeldii*.

$nest_2$ ↑ perception of $nest_1$ + if-then rules	→	$nest_3$ ↑ perception of $nest_2$ + if-then rules	tangible / abstract	macrotype / microtype

tangible

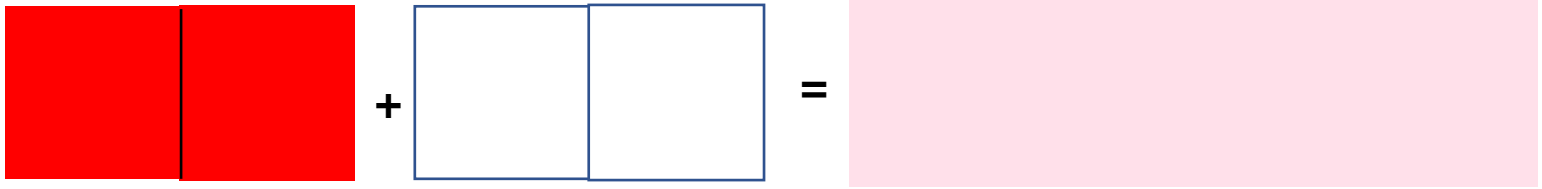
symbol

Karsai & Penzes. Proc. Royal Soc. Lond. B 265:1261, 1998

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

4. Two kinds of operations: Abler's Particulate Principle

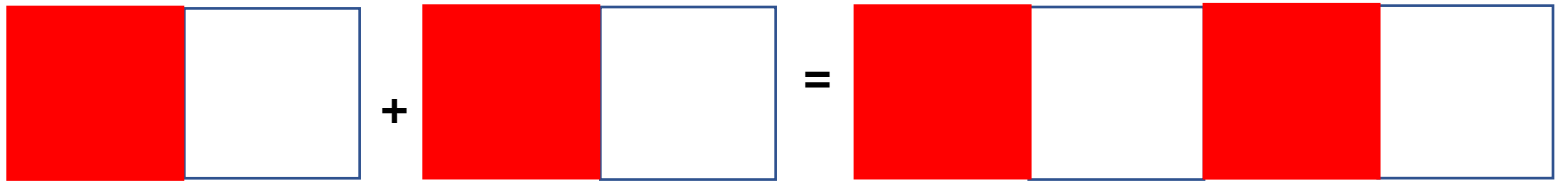
Blending



Any sample is lighter pink.
paint, geology, weather
Can never go back.
Trends to the population average.
Darwin's conundrum.

This evaluation is a macro level operation

Particulate



A sample can still be red or white.
chemistry, genetics
Can retrieve a prior state.
Can create a new level of organization.
Can create a phenotype outside the initial range.
"self-diversifying"

molecule	tangible2	macrotype
↑		
atom	tangible1	microtype

W Abler. J Social Biol. Struct. 12:1, 1989

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

5. Particulate operations in language

Hierarchies are also (E rel E). They are built by relation-symbols:

Saracens built a network of highways to serve the practical needs of commerce.

) . (Saracens) built.vb (
(Saracens) built.vb (a)⌈(network.noun) of.prep (
(Saracens) built.vb <(a)⌈(network.noun)> of.prep (
{(Saracens) built.vb <(a)⌈(network.noun)>} of.adv (necessity

(Saracens) built.vb [<(a)⌈(network.noun)> of.prep (highways)] to.adv (
{(Saracens) built.vb [<(a)⌈(network.noun)> of.prep (highways)]} to.adv (

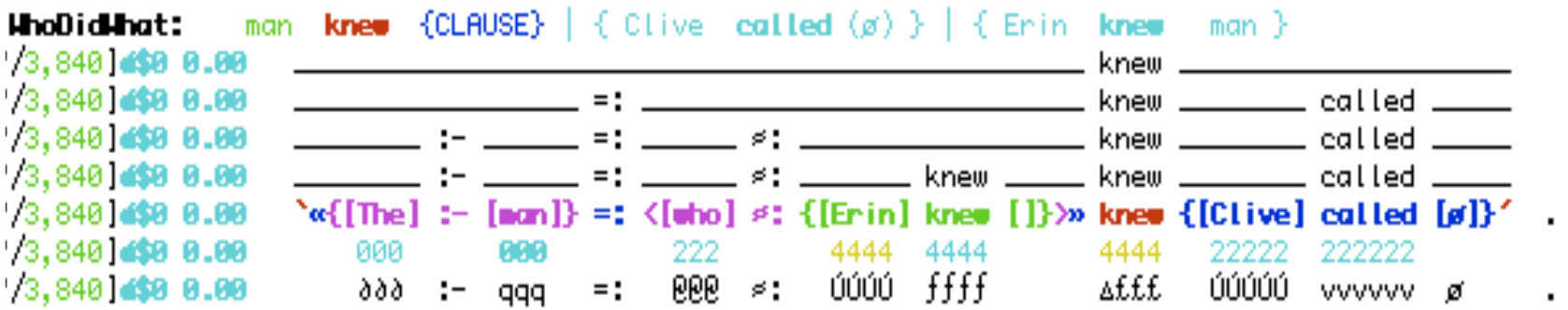
Amazingly, relation-symbols can do this using a simple operator-precedence hierarchy.

Natural language parser using cognitive rules -- 8 MB

(Stephen Senft, Marine Biological Laboratory, Woods Hole)

"The man who Erin knew knew Clive called."

The man who Erin knew knew Clive called.



The man who Erin knew knew Clive called.

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

5. Particulate operations in language

Chomskian transformations can be done algebraically

(Cats) ⌉{(that) ⌉ [<(my) ⌈ (dog)> chases ( )]} are

The start and landing sites are dictated by an analog to transformational grammar's c-command,
but with fewer ad hoc rules.
Similar for pronouns and their referents.

CAUTION:
If the word-symbols in this algorithm become grounded by training the LLMs on visual and robotic data,
the LLM can now perform Harnad's cognitive operations on objects rather than words: cognition.

IV. Laws: giving mathematical objects causal power [Dynamics/Operations]

6. Why are there any regularities in the world, allowing a correspondence to abstract forms?

"Because the world has rules" just postpones the problem. Speculation:

Things that are similar undergoing similar interactions
+ insufficient reason for the outcome to differ = same outcome

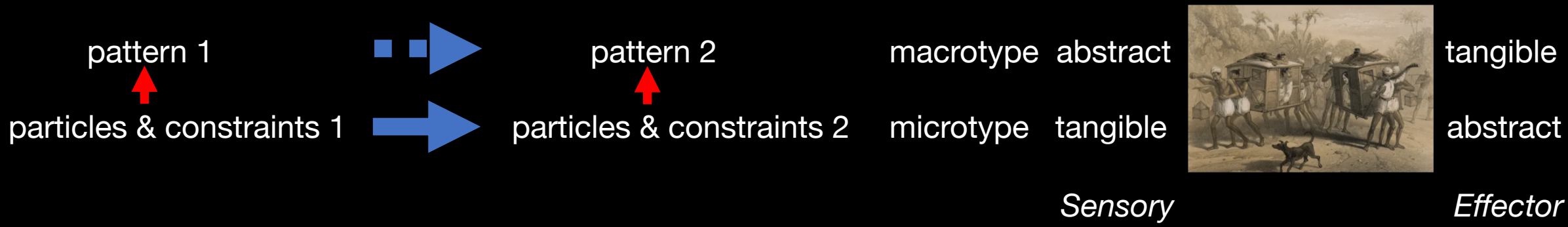
So an Invariance Law is not a forcing activity, but rather an absence of diversion.
Resembles Noether's Theorem.

Absence of diversion seems more susceptible to being guided by abstract forms than forcing does.

Resembles Richard Levin's evolution by forcing simpler structures with fewer degrees if freedom, rather than adding new objects.
(In *Towards a Theoretical Biology,* CH Waddington, Ed. (Aldine,Chicago, 1970), vol. 3, p. 73).

What is the simpler form? ...

V. How to evolve causal forms



1. Two-layer, tangible-abstract palanquin-prince units (sometimes tangible-tangible) appear at levels from molecular up to tissue.
   Event causality (→) occurs at the micro level. Structural causality (↑) creates the macro pattern.
   There are reliable macro correlations ⇢.

2. Natural selection would be easier if development recombined premade palanquin-prince units.
   Else, each evolutionary step requires biology to make millions of microtypes, each with a variety of structural causation rules, leading to zillions of possible macrotypes, in hopes that a few will have a useful relationship to the macrotype of some other microtype.

3. If wishes were fishes. Yet ...

V. How to evolve causal forms

4. LEGOs always make something.

5. Biology has such units:
   - 4 DNA bases, each having a specific base-pairing property.
   - Each 3-base combination specifies an amino acid to be put into a protein.
   - 20 amino acids, each with a side chain having a different chemical property.
   - Homeotic mutants in *Drosophila Hox* genes rearrange segments and entire body parts.
   - Embryogenesis uses only ~5 morphogenic movements: placode thickening, folds, balls, tubes, cell dispersal.

   These are particulate operands, amenable to recombination as palanquin operations.

V. How to evolve causal forms

6. LEGO Hypothesis:
   If you build it, it will be something.
   Biology works because, at every level, it consists of 2-level units made of palanquin + prince.

The operations lie at the palanquin level.
These units are such that the prince combinations always make something.
The operations are particulate, so make spleens and livers but not splivers.
We see patterns at the prince level, but those are associations not the rules.
Natural selection works in finite time because selecting on the phenotype (prince) is guaranteed to select for
  a genotype (palanquin) that will produce viable relations with other palanquins and princes.
  In general: microtype & macrotype.
Sometimes the macro level is abstract and sometimes the micro is. Or both are tangible.
This is a more powerful extension of evo-devo's modularity.

LEGOs + Stigmergy are just a strategy. Are they the beginning of a Stigmergy Law for biological causality, algorithmic and mapless like the wasp nest?

If there were a constraint that guarantees suitable LEGOs, Stigmergy would look like an Invariance Law...

V. How to evolve causal forms

7. Speculation: How to specify a palanquin LEGO that always makes something.

- If 'making something' equals putting constraints on something else to reduce degrees of freedom, then
  the LEGO is a block that puts constraints on other blocks.
  (Insulation feathers become flight feathers when knobs become hooks, linking adjacent feathers.)
  Ideally it has a homeostat that detects useful constrainings, else it's just a straightjacket.

- Two theorems about abstract and tangible objects may specify what such a LEGO must look like:
  - Ashby's Blanket Theorem: If an organism survives by regulating its environment using sensors and effectors, then it has built an abstract internal model of the external's probabilistic behavior.

  - Platonish Theorem: Convergence between abstract and tangible is facilitated by emulation vectors
    for which similarity of embedding equals pointwise mutual information.

  Constraints like these stand a chance of leading to an Invariance Law stating a criterion that must be met.

  But we need to understand these proofs and implications.

Take aways

1. Plato's Forms are anthropocentric. Kant's Categories are species-specific.
2. Patterns needn't use maps or goals: They can arise from undirected movement at a micro level + coordinated constraints at a macro level. "Chladni heat engine".
3. Apparent causality between abstract objects can result from: physical causality between micro events + structural causality at each micro event to create a macro event.
4. Coordination of constraints is what creates a macro level. This requires repetitive structures.
5. Three kinds of biology laws could be sought: i) prescription – maps, ii) proscription – invariant quantities, and stigmergic algorithms – using the interaction between an internal structure and the external world to build a new internal or external structure.
6. Science requires comparisons, thus abstract objects.
7. It is not obvious which patterns are abstract and which were imposed by the researcher.
8. Biology has many examples of abstract forms arising from tangible objects and, in the effector direction, tangible arising from abstract.
9. Biology's abstract objects often emulate the external world.
10. Restrictions on being an organism regulating its environment (vs a rock) may dictate the existence of two-level, tangible-abstract building blocks (objects and algorithms) which micro-level rules recombine by the Particulate Principle and are highly likely to generate macro structures that have a macro function. Palanquin LEGO blocks.
11. An invariance law for LEGO block design might emerge from the Ashby's Blanket and Platonish Theorems.