How do biology processes differ from those of physics?

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World Science Festival

World Science U for a Day

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Outline:

1: The nature of Physics

2: The nature of life

3: Modular Hierarchies

4: Origin of Information

5: Top-Down effects

6. Conclusion

1: Nature of Physics: Fixed physical interactions

- Given
  (a) the context
  (b) the initial conditions,

the outcome (in classical physics) is inevitable.

- There is no arbitrariness about it.

- For example gravity is an inverse square law. No options.

- In the quantum case, the individual outcomes are random but the statistics are highly predictable.

Intention or choice do not enter in either case.

Logic of Physics

Physical laws determine evolution of a physical system in a purposeless inevitable way.

Let the relevant variables be X and the evolution dynamics be given by the context C set by initial and boundary conditions,

then that dynamical law determines later states from earlier states:

e.g. $X = X_0 + V_0\, t - \frac{1}{2}\, g\, t^2$

for a freely falling body subject only to a gravitational field g

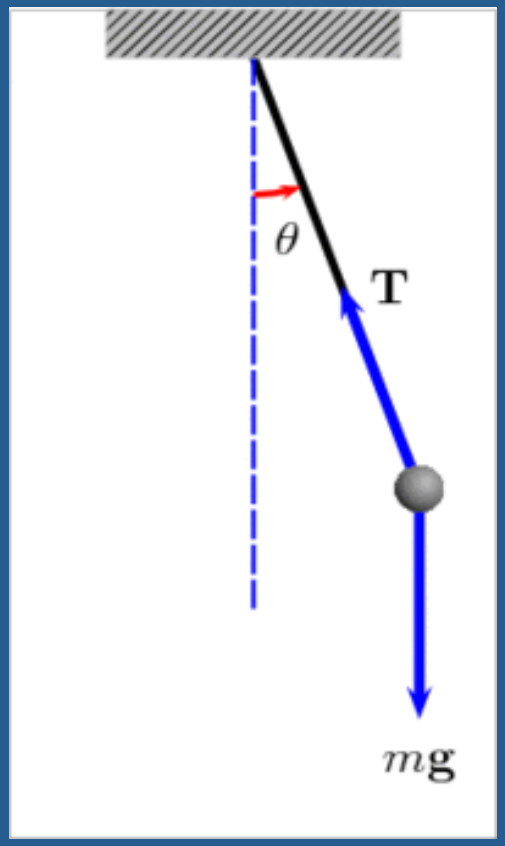
Testable repeatable outcomes.

"The language of nature is mathematics" (Galileo)

Experimental tests:
We find out what they are by experiment

Galileo demonstrates the inclined plane
Fresco by G. Bezzuoli, 1841

Pendulums



Fixed physical interactions

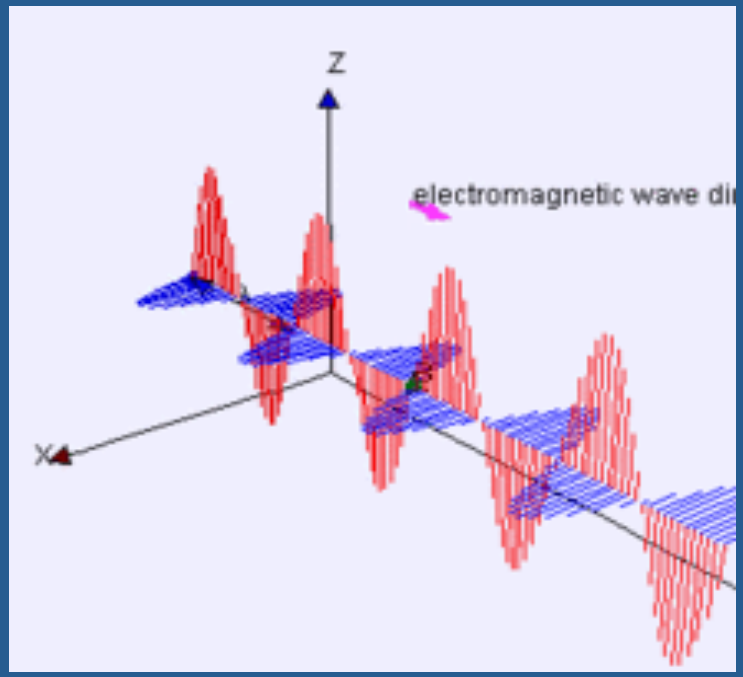
- The key point is that in physics there are fixed interactions that cannot be altered, such as the gravitational and electromagnetic interactions.

Gravity is an inverse square law. There is nothing you can do about it.

- We can however decide what they will act on,

E.g. we can construct computers, electric motors, telephones, automobiles, and so on.

Maxwell's equations predict electromagnetic waves



Waves made of transverse electric and magnetic fields

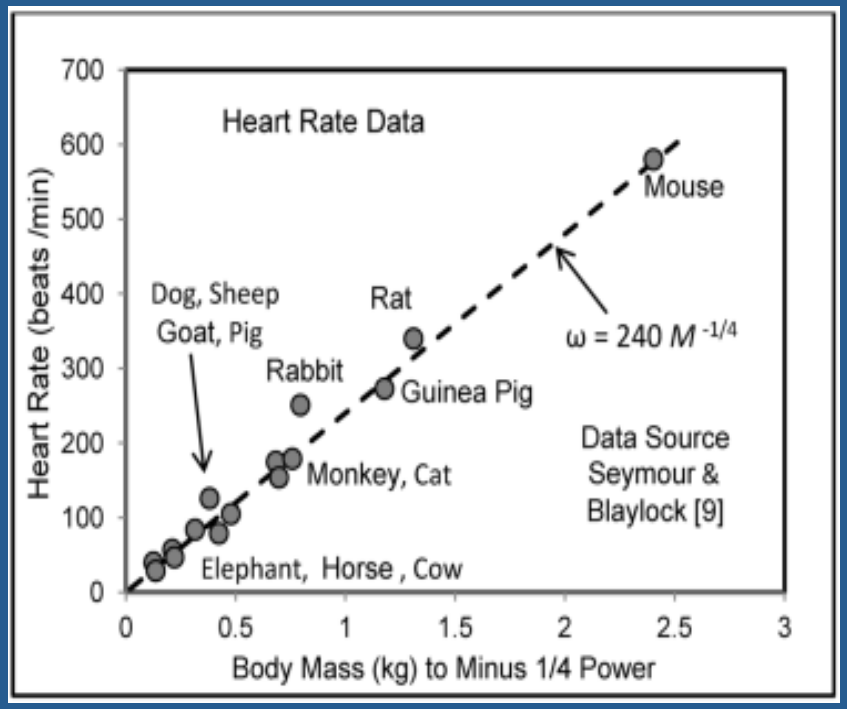
Wavelength mathematically arbitrary

Travel at the speed of light

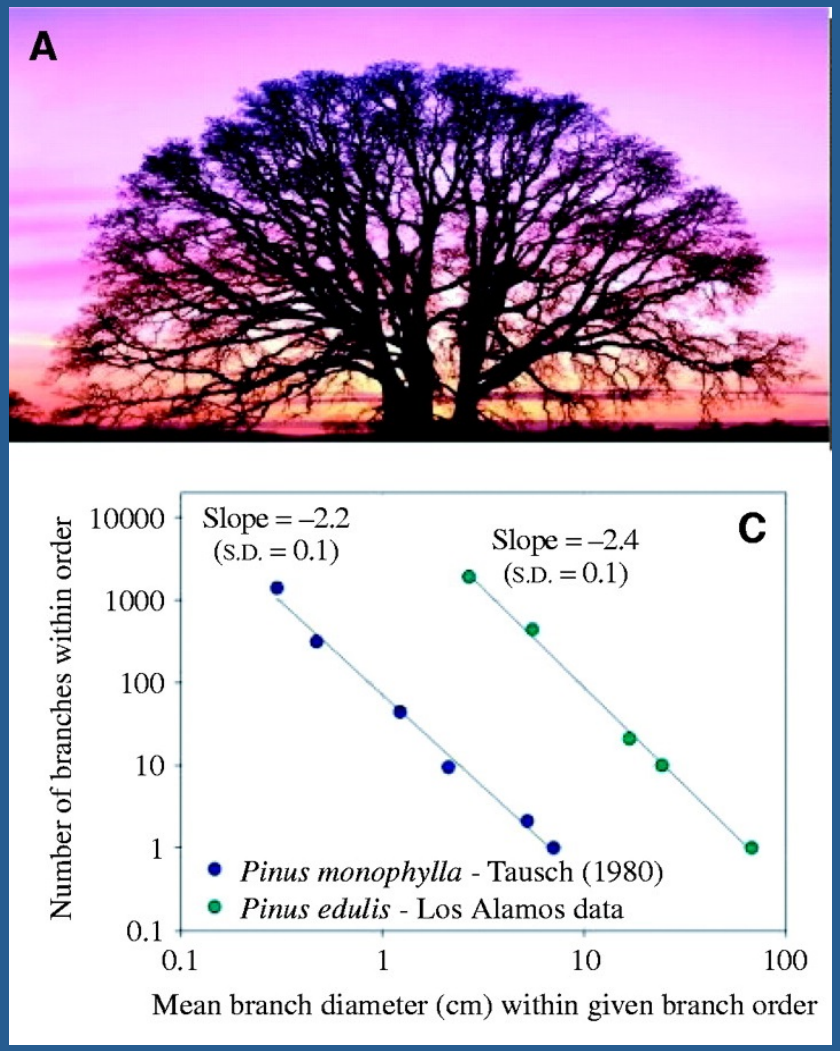
Can carry arbitrary information

Physics of life

Scaling laws



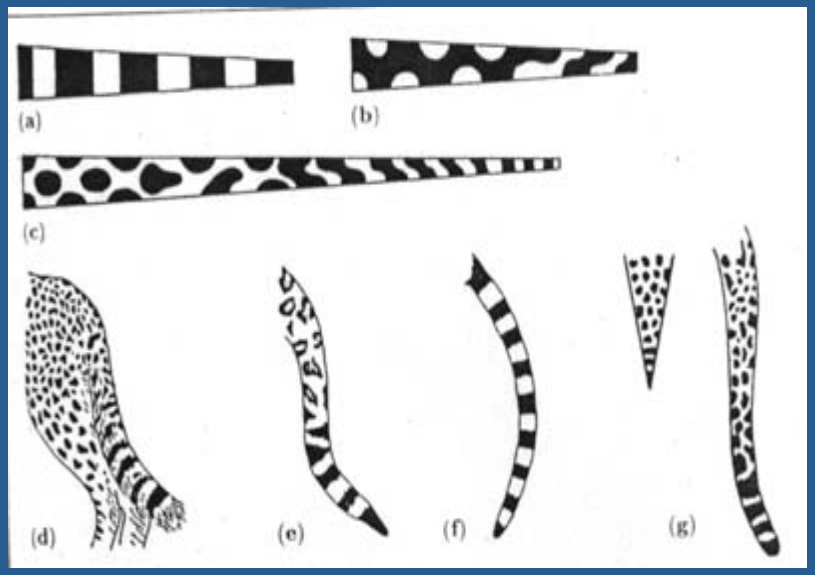
mdpi.com/2079-8954/2/2/168/htm

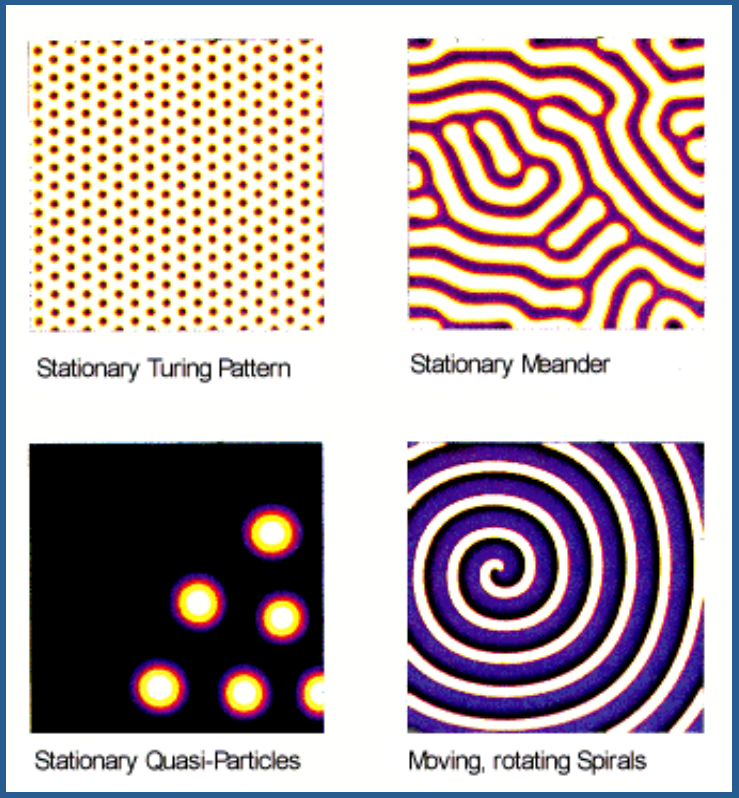


http://jeb.biologists.org/content/208/9/1575

Physics of life

Reaction diffusion equation
(Alan Turing)





Production, diffusion and
Decay of interacting reactants

www.sjsu.edu/faculty/watkins/murray.htm

But does this take biology seriously?

Physics restricts biology:

C S Cockell: "The Laws of Life" *Physics Today March 2017:43-48*

- *Why no wheels?*
- *How to fly?*
- *Scaling laws*
- *Energy collection needed (2nd Law)*

- But none of this gets to the heart of what life is about

2: Nature of Life

L H Hartwell, J J Hopfield, S Leibler and A W Murray (1999) ``From molecular to modular cell biology'' *Nature* **402** Supplement: C42 -C52.

- "Although living systems obey the laws of physics and chemistry, the notion of function or purpose differentiates biology from other natural sciences. Organisms exist to reproduce, whereas rocks and stars have no purpose.

- Selection for function has produced the living cell, with a unique set of properties that distinguish it from inanimate systems of interacting molecules. Cells exist far from thermal equilibrium by harvesting energy from their environment.

- They are composed of thousands of different types of molecule. They contain information for their survival and reproduction, in the form of their DNA".

Processes of life:

Homeostasis: regulation of the internal environment to maintain a constant state

Organization: being structurally composed of one or more cells — the basic units of life

Metabolism transformation of energy to maintain internal organization and to do work. All living things require energy to continue existing.

Growth A growing organism increases in size and organisation of its parts through developmental processes.

Adaptation: the ability to change over time in response to the environment.

Response to stimuli: ranging from the reaction of a unicellular organism to external chemicals, to complex reactions involving all the senses of multicellular organisms.

Reproduction: the ability to produce new individual organisms,.

Logic of life:
Choosing between options

These complex processes, enabled by physiological systems, all have underlying physical and chemical bases,

They all adapt life to its physical, ecological and social environment.

Thus they monitor the environment and respond to it, varying their responses accordingly

They do so via sensory, signalling, and control mechanisms that are essential to maintaining life

This uses energy, but that is incidental to their purpose

Information use

Principle 1: Life and Information *usage*

All biological life is based on function or purpose, and at the higher levels of emergence, intention.

- *Deployment of resources to attain specific purposes is dependent on acquisition, filtering, classification, and storage of information,*
- *which enables choices of future actions to take place on the basis of reliable prediction of possible future outcomes.*
- *This is a logical process. It can be realised in different ways in physical terms.*

Information usage logic

Principle 2: Logic of information usage

Information use at each level of a logical hierarchy is based on contextually informed logical choices of the form

{GIVEN CONTEXT C, IF T(X) THEN F1(Y), ELSE F2(Z)}, **(1)**

where T(X), F1(Y) *and* F2(Z) *are arbitrary functions of variables X, Y, Z,*

including logical operations (*AND, OR, NOT, NOR, etc*).

It is based in physics but different than the logic of physical laws per se.

The key point is the arbitrariness of these logical and mathematical functions

Example: bacterial motility

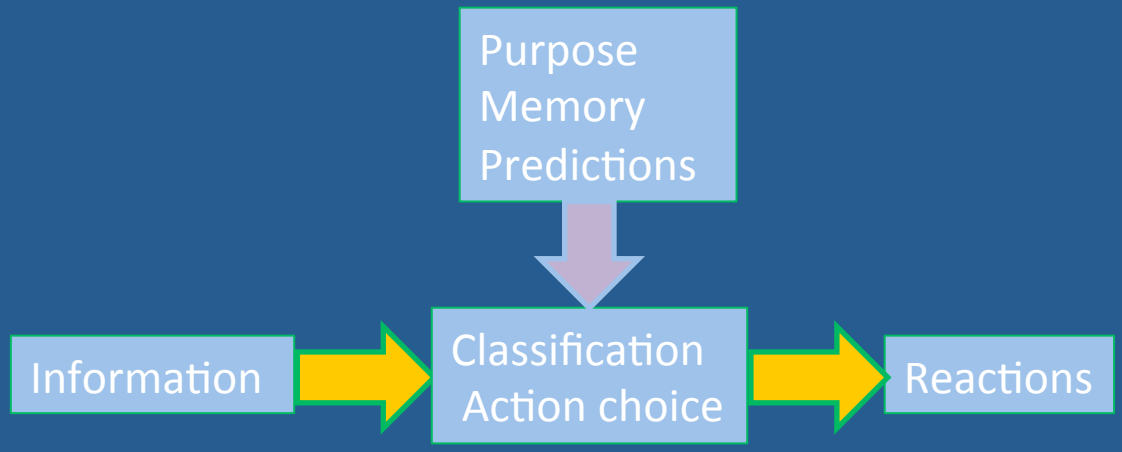
Level 1: Move towards nutrients, away from poisons

Level 2: Detect gradients of chemicals in environment. Determine desired motion direction.

Level 3: Determine signals to send to signalling network for flagella so that cells can move toward favourable environments and away from unfavourable ones by controlling tumbling

The logic IF POISONOUS THEN MOVE AWAY is implemented via particular network motifs, e.g. the feedforward loop network motif (Mangan and Alon, PNAS 21: 11980 (2003)).

Information usage: at the psychological level



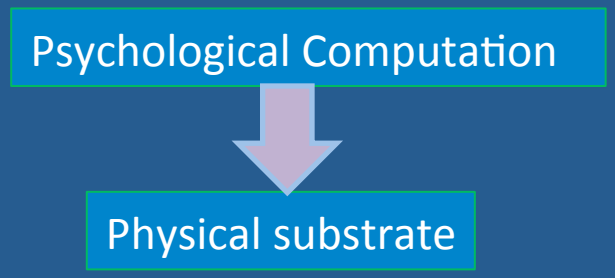
Information use to plan action outcomes.

*Prediction leads to outcomes (*J Hawkins, *On Intelligence)*

e.g. IF I take the expressway THEN I will get there sooner

The logic of these processes is at the psychological level, relying on physical, biological, and social information at that level. The mechanism to enable this to happen is realised at the lower physical levels.

Key Point: Multiple realisability



Philip Anderson (*Proc Nat Acad Sci* **92** (1995) 6653):

"The rules governing computation do not vary depending on the substrate in which they are expressed;
Hence they are logically independent of the physical laws governing the substrate"

"This principle of emergence is as pervasive a philosophical foundation of the viewpoint of modern science as is reductionism. It underlies for instance all of biology"

3: Modular Hierarchies

Principle 3: Complex emergence is based in modular hierarchies

- *All genuine complexity is based in modular hierarchical structures, where a complex task is broken up into simpler tasks that when done together coherently enable the complex task to be accomplished.*

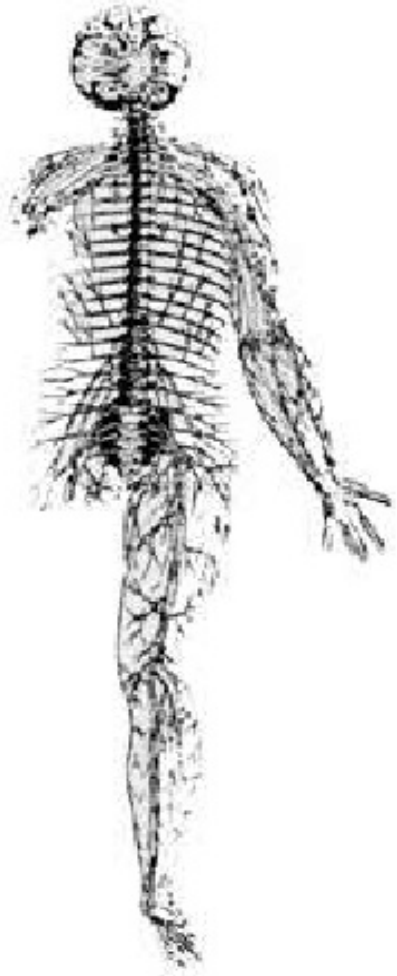
- *Strongly bound units (modules) accomplish the simpler tasks, hiding their interior processes from the exterior (abstraction).*

- *Thus simple logical operations are combined in complex ways to give complex higher level logic*

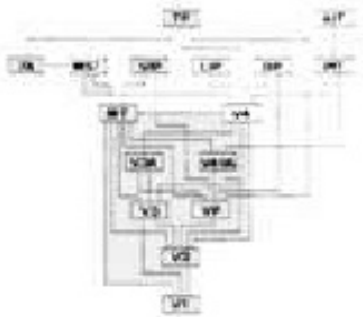
H A Simon: *On the sciences of the artificial*
G Booch: *Object Oriented programming*

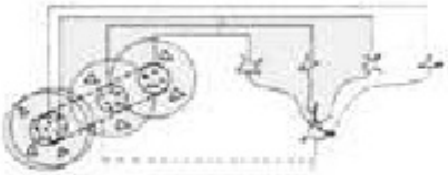
The nervous system

Structural organization of levels in brain (Churchland)



1 m	CNS
10 cm	Systems
1 cm	Maps
1 mm	Networks
100 μm	Neurons
1 μm	Synapses
1 Å	Molecules





The Hierarchy of Structure and Causation

1. *Sociology/Ecology/Economics/Politics*
2. *Psychology/Botany/Zoology/*
3. *Physiology*
4. *Cell biology/ Neurology*
5. *Genotype/Biochemistry/Molecular biology*
6. *Chemistry*
7. *Atomic Physics*
8. *Particle physics*

The human sciences hierarch of structure and causation.

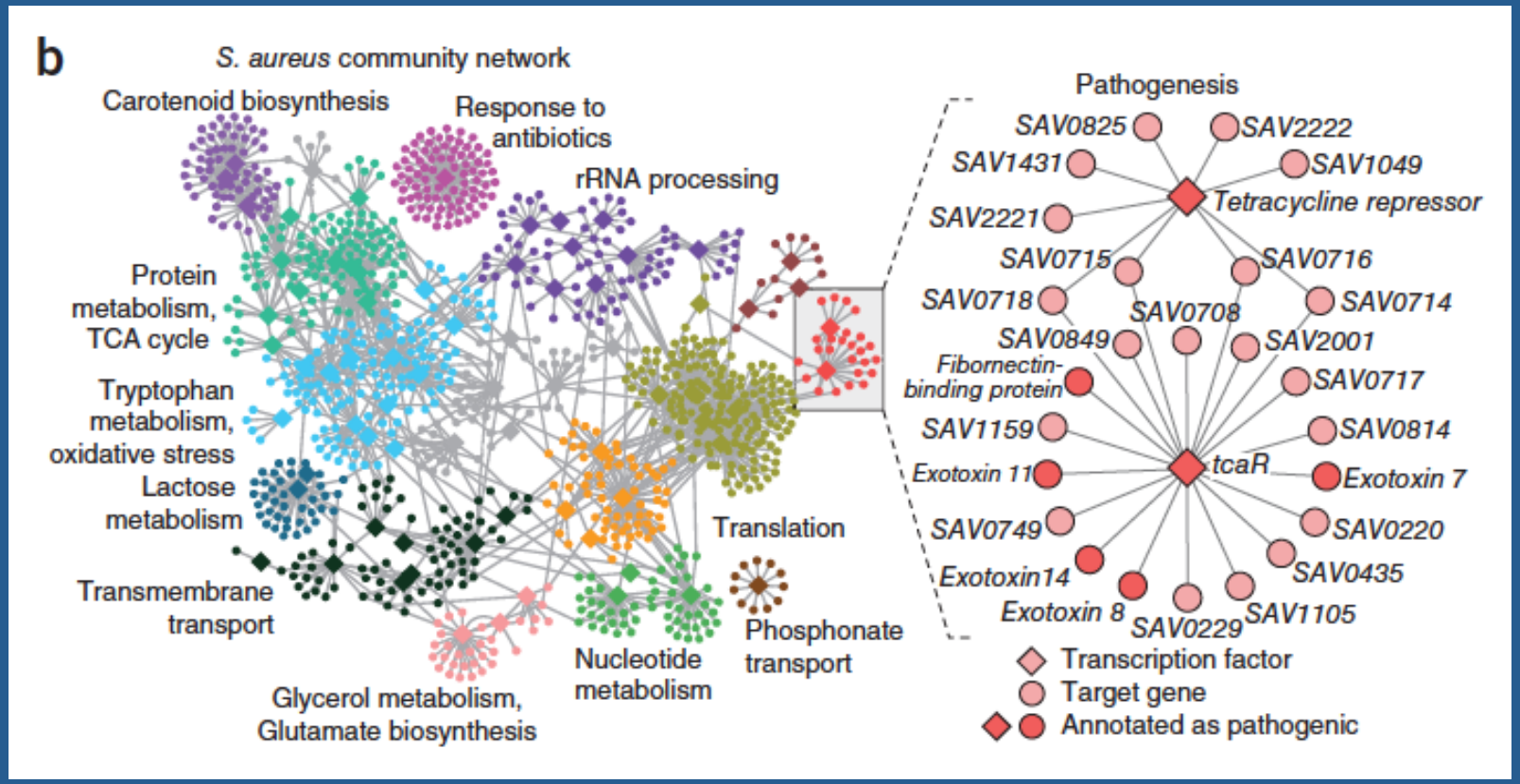
The lower levels are physical, but the higher levels have abstract elements such as values, thoughts, and social roles, which are causally effective in the hierarchy.

Networks

- Simple elements are joined together to make networks of interacting elements
- Higher order logics thereby emerge from simple logical elements
- Nodes represent the elements, which have specific equations describing how they work (binary logic or more graded)
- Links represent the interactions: again binary, or graded (coefficient representing strength of interaction)

Overall, logical elements are combined not by coarse graining but by black boxing and abstraction

Hierarchical structure of a gene regulatory network



Networks: graph theory

- *Nature Reviews Neuroscience* **10**, 186-198 (March 2009)
- Complex brain networks: graph theoretical analysis of structural and functional systems Ed Bullmore & Olaf Sporns

Recent developments in the quantitative analysis of complex networks, based largely on graph theory, have been rapidly translated to studies of brain network organization. The brain's structural and functional systems have features of complex networks — such as small-world topology, highly connected hubs and modularity — both at the whole-brain scale of human neuroimaging and at a cellular scale in non-human animals.

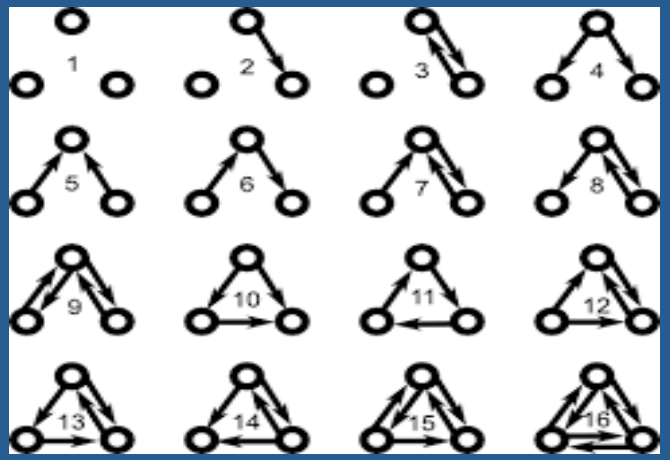
➔ **Statistics of networks**

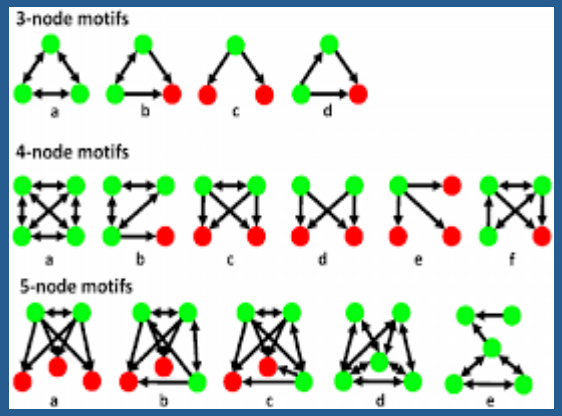
Networks and Network Motifs

Network motifs recur and carry out specific functions (Uri Alon)

They have specific equations describing how they work

- Uri Alon: ***An Introduction to Systems Biology: Design Principles of Biological Circuits***
-





Network motifs in the transcriptional regulation network of *Escherichia coli*

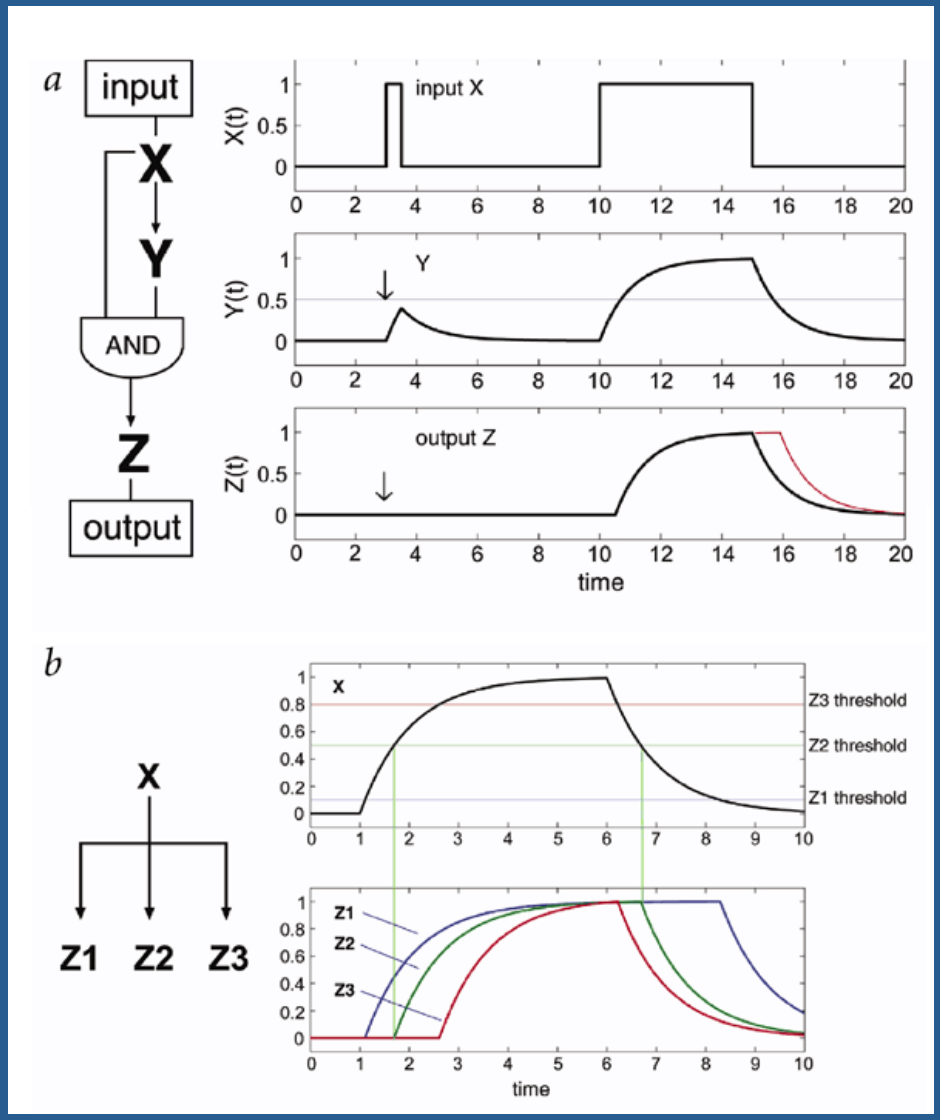


Fig. 2 ***a***, Consider a coherent feedforward loop circuit with an 'AND gate'– like control of the output operon Z.

This circuit can reject rapid variations in the activity of the input X, and respond only to persistent activation profiles.

b, Dynamics of the SIM motif. This motif can show a temporal program of expression according to a hierarchy of activation thresholds of the genes.

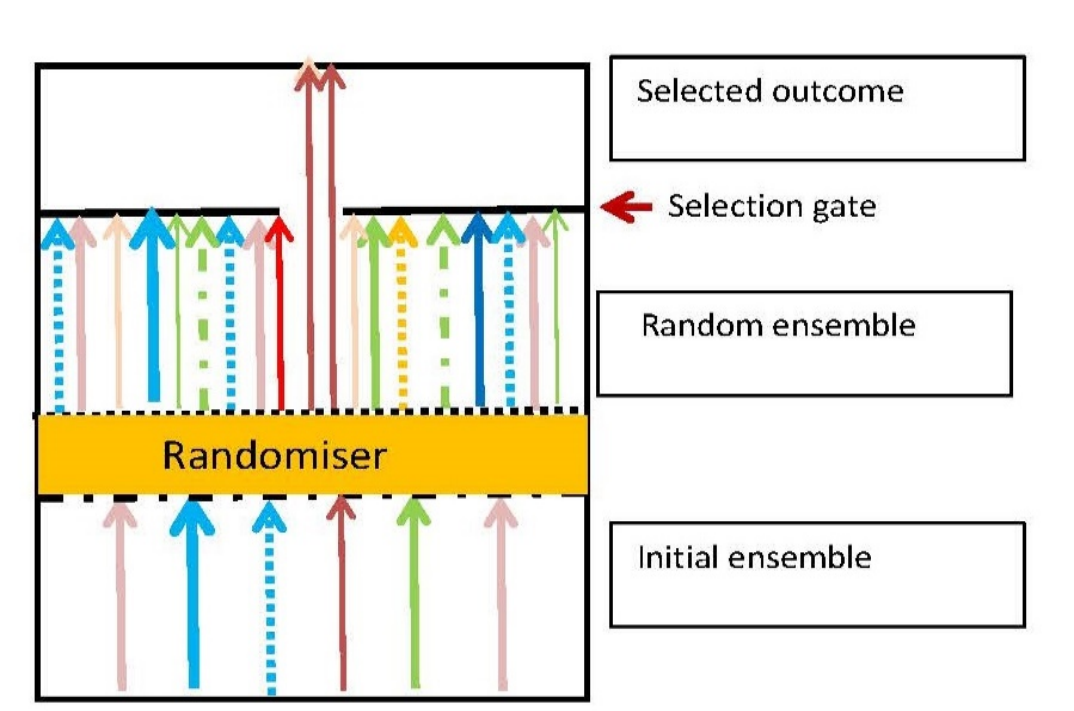
When the activity of X, the master activator, rises and falls with time, the genes with the lowest threshold are activated earliest and deactivated latest.

4: Origin of Information

Principle 4: Origin of Information

- *Information origination is via processes of adaptive selection both in the logical hierarchies (learning and experimentation) and in the implementation hierarchy (via natural selection or engineering design, depending on context).*
- *In the biological case, this process takes place in a contextual way through adaptation to the physical, ecological, and social environment of developmental.*
- *This is a multi-level process, with higher level needs driving lower level selection.*

Origin of Information



The basic selection process. *An incoming random ensemble is filtered to produce an outgoing ordered ensemble, adapted to the environment via selection criteria.*

Example: Maxwell's demon

Origin of Information

The logic of the process is a special case of that discussed in Principle 2:

Context C, selection principle S, ensemble E of entities X. Then

$$\Pi_S(X)\text{: \{IF NOT S(X:C) THEN DELETE X\}} \qquad (2)$$

hence the effect on the ensemble E(X) is to purify it:

- All the members X of the new ensemble $\hat{E}(X)$ obey the selection condition S(X:C).

A simple example in the logical case is deleting emails or files on a computer.

It takes place in biology through Darwinian selection,

In the logical case it is the process of discovery and learning

Many levels interact

Vision gives great advantage to individuals

For enhanced survival: Need visual system

➔ Need eyes, optic tract, thalamus, brain

➔ Need neurons, synapses

➔ Need developmental systems to produce these

➔ Need whatever genome will do the job: must select for (Wagner)

- Gene regulatory networks
- Signal Transductions networks
- Metabolic regulatory networks
- Specific Proteins (e.g., haemoglobin, voltage gated ion channels, kinesin)

Vast number of different genomes can do the job (Wagner): Any one of them must be selected for by exploring the possibility space

They do not come into existence in a top down way: mutations and drift occur

But they get selected because of the higher level function they enable

Emergent Laws

Adaptive selection is an emergent biological process

It acts at all levels: groups, organisms, systems, cells, interaction networks, genes, molecules

- It is based in physical processes, but is not itself a physical law: it is an essentially biological effect

- It is not directly implied by or deducible from the equations of the standard model of particle physics

- Whether in the Darwinian case, or in the case of learning

Adaptive selection is a top down process

Natural selection is a top down process adapting animals to their environment, thereby altering the details base-pair sequence in DNA; thus

- *"Evolution is essentially a process in which natural selection acts as a mechanism for transferring information from the environment to the collective genome of the species"*

  (Stone: *Information Theory*:188).

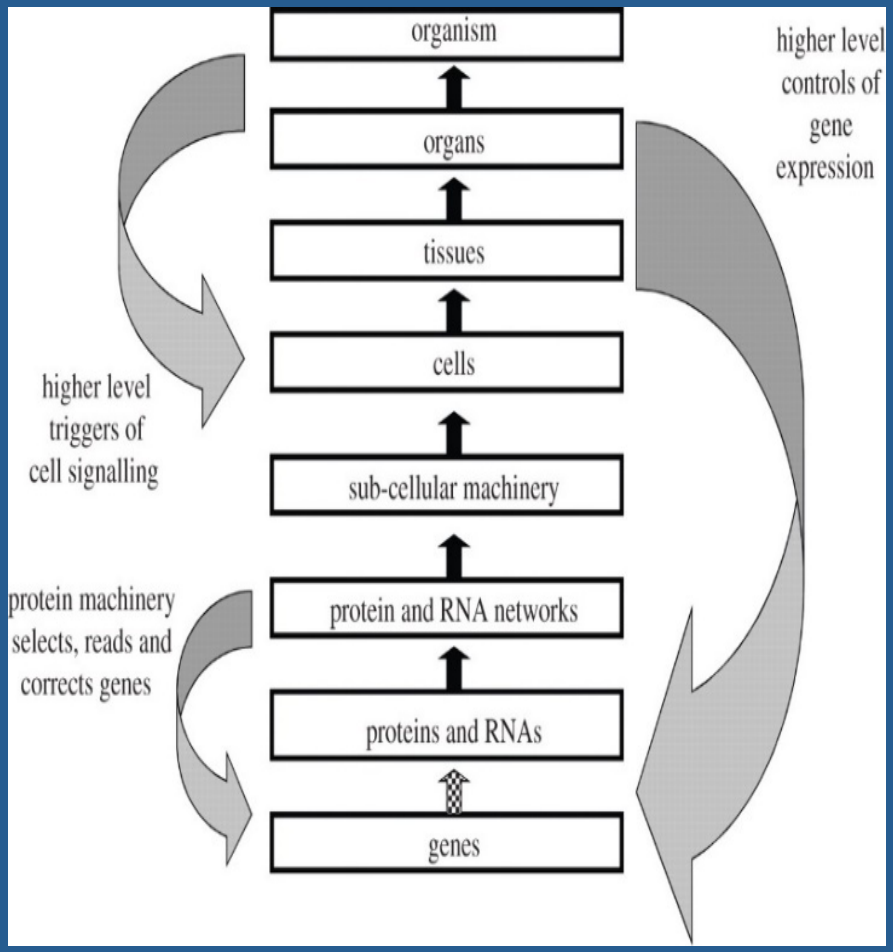
5: Top-Down effects

Principle 5: Top-down effects in modular hierarchies.

In an implementation hierarchy, the processes of strong emergence and associated higher level information storage and utilization are only possible via top down realisation of higher level requirements at lower levels, with multiple such realisations possible .

In this way the lower levels carry out the work, but the higher levels decide what will be done.

Top-Down effects



Top-down effects take place as well as bottom up effects. *This is the case of physiology as presented by Denis Noble (2012), based on his detailed studies of the heart.*

Metabolic pathway regulation:
Transcription factors TF
(turn genes on and off),
Metabolites X (needed),
Enzymes E (speed reaction)

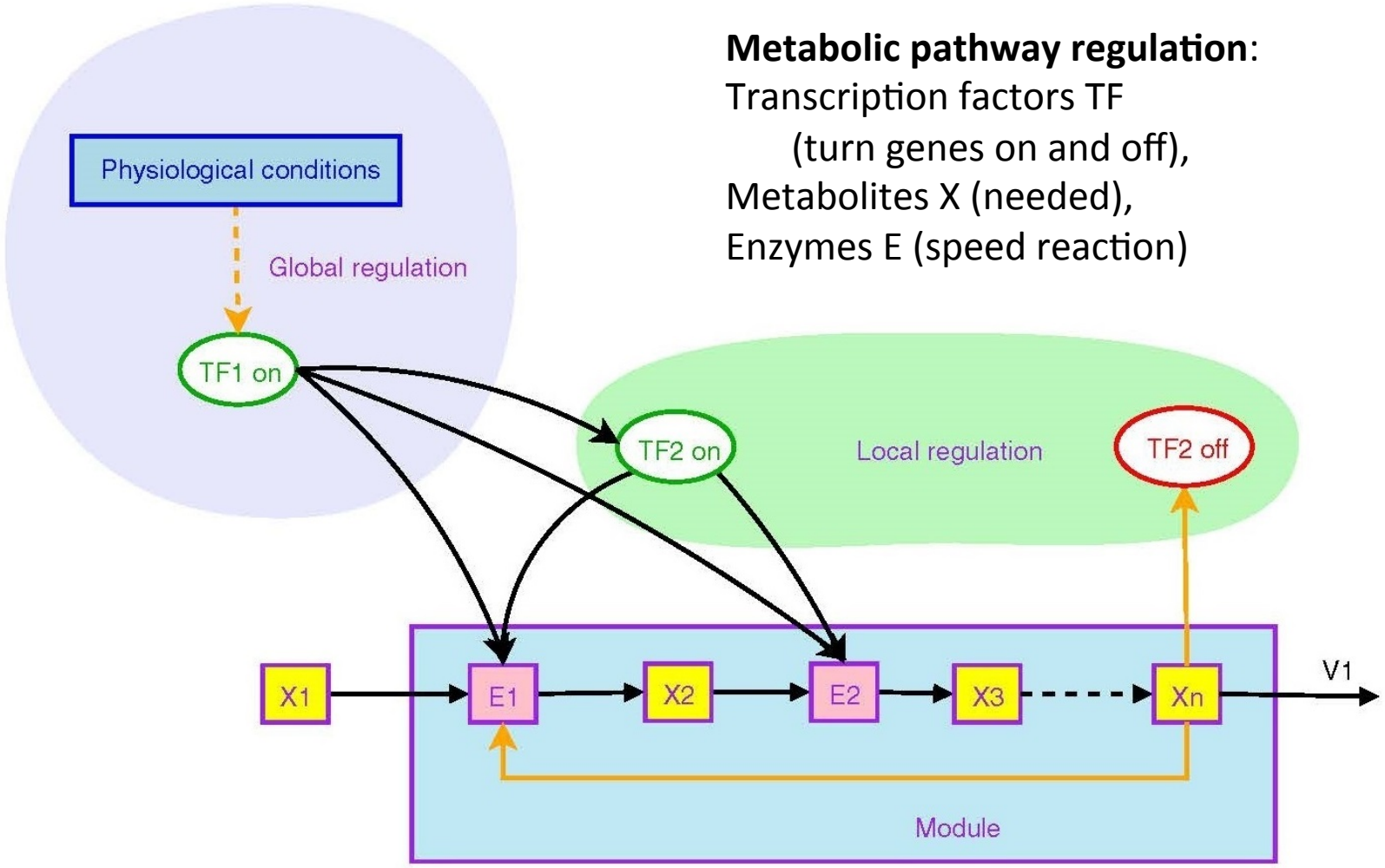


Figure 3
Global and local regulation of a metabolic pathway. Yellow (resp. pink) boxes represent metabolite (resp. enzyme) pools. The transcription factors are represented by ellipses. Green and red indicate that the transcription factor is "on" and "off", respectively, where "on" means that the transcription factor is able to bind to DNA. The local transcription factor (TF_2) is sensitive to an intermediate metabolite (X_n), and modulates the synthesis of enzyme(s) involved in the pathway. The global regulator TF_1, sensitive to another signal, can modulate (*i*) the synthesis of intermediate enzymes; (*ii*) the synthesis of the local transcription factor TF_2, or (*iii*) both.

The levels in a conscious action

Level 1: "I'm going to bake a cake": ***This decision drives what happens***

Level 2: The recipe

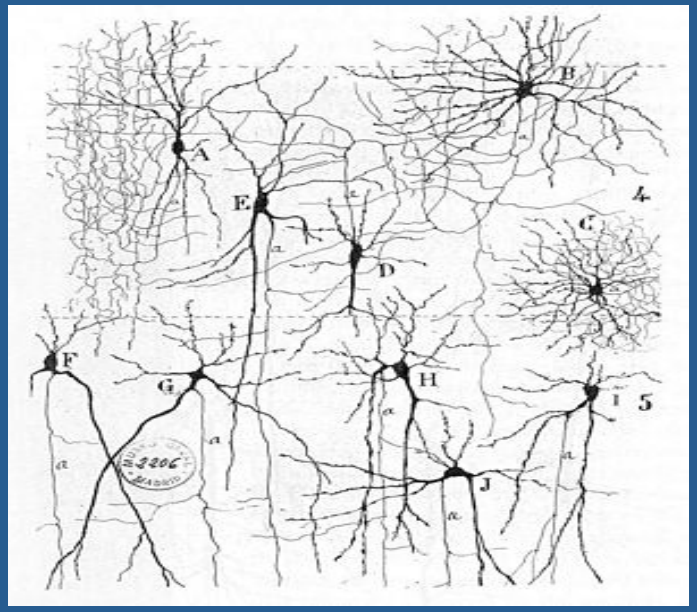
- ***Get Ingredients***
- 2 cups all-purpose flour, 1 teaspoon salt, 1 teaspoon baking powder, 2 teaspoons baking soda, 3/4 cup baking cocoa, 2 cups sugar, 1 cup canola oil, 1 cup brewed coffee, 1 cup milk, 2 large eggs, 1 teaspoon vanilla extract

- ***Directions***
- Preheat oven to 325°. Sift together dry ingredients in a bowl. Add oil, coffee and milk; mix at medium speed 1 minute. Add eggs and vanilla; beat 2 minutes longer. (Batter will be thin.)
- Pour into two greased and floured 9-in. round baking pans (or two 8-in. round baking pans and six muffin cups).
- Bake 25-30 minutes. Cool 10 minutes before removing from pans. Cool on wire racks.
- Meanwhile, for icing, combine milk and flour in a saucepan; cook until thick. Cover and refrigerate.
- In a bowl, beat butter, shortening, sugar and vanilla until creamy. Add chilled milk mixture and beat 10 minutes. Frost cooled cake. **Yield:** 12 servings.

The levels in a conscious action

Level 3: Brain networks (neural networks and oscillatory bindings):

neurons in networks



spike chains, logic gates in cortical columns

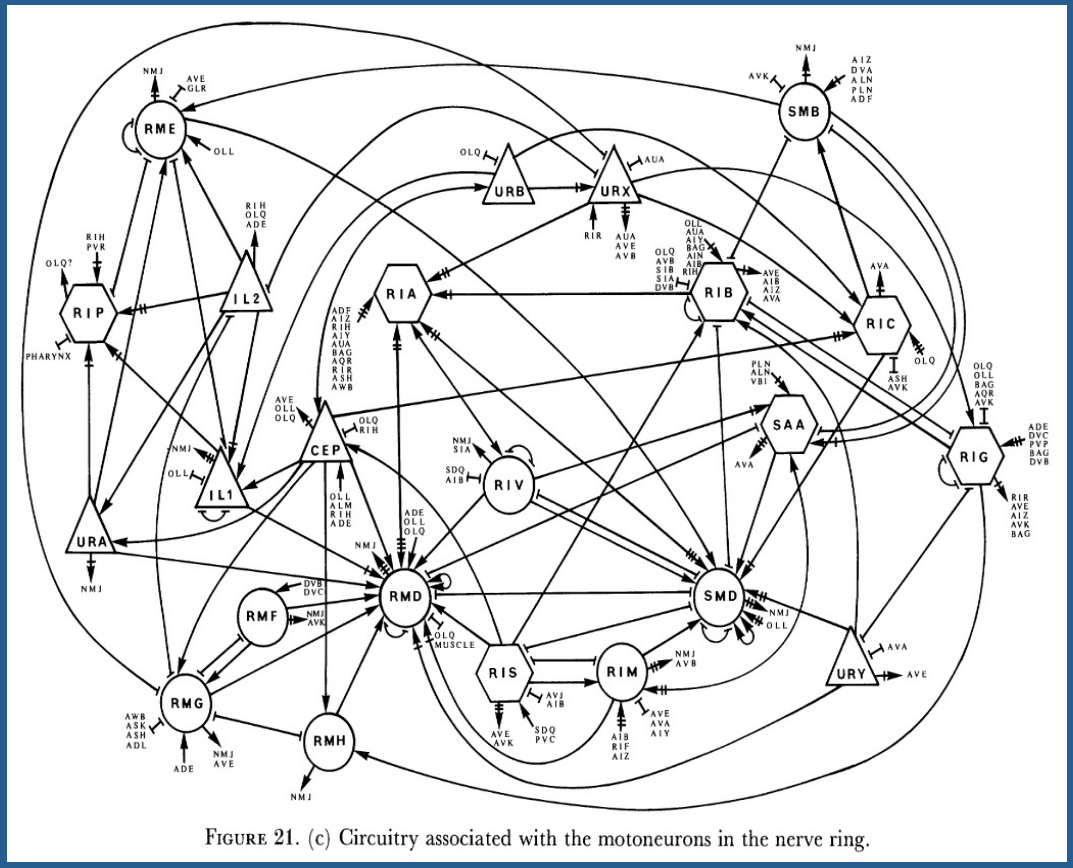


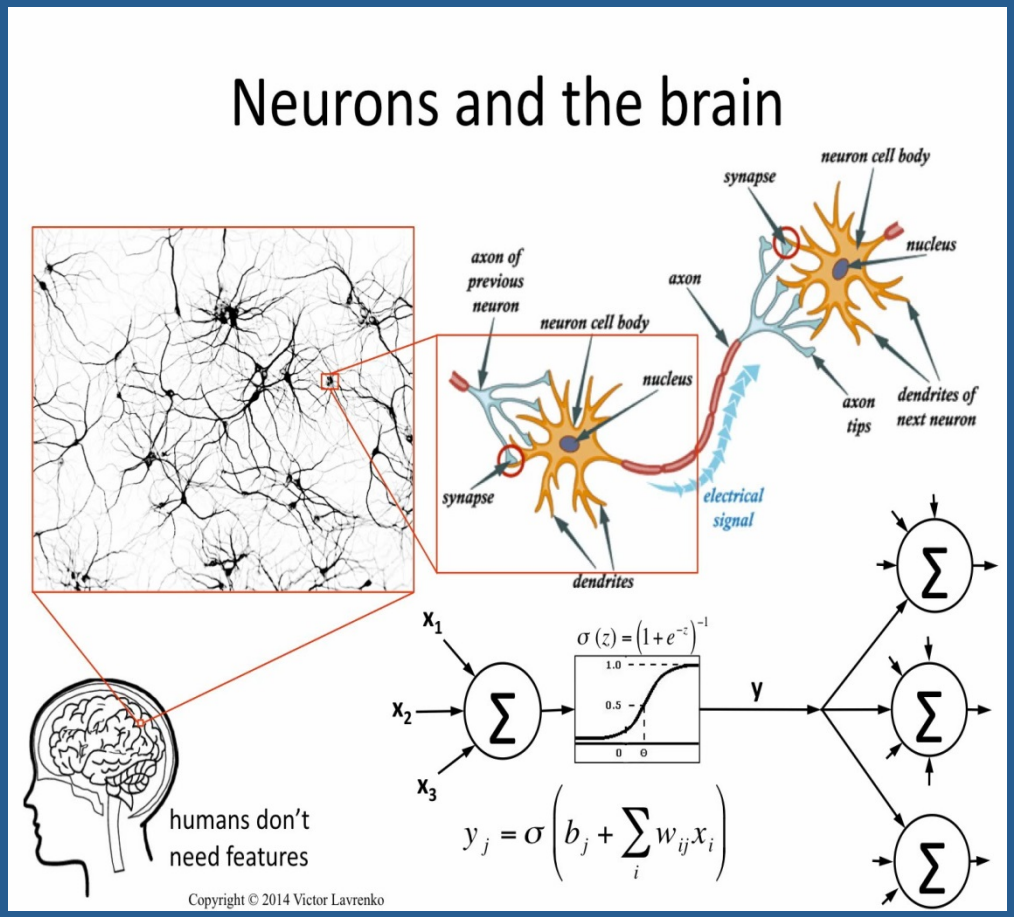
FIGURE 21. (c) Circuitry associated with the motoneurons in the nerve ring.

No one knows how thoughts are represented by spike chains

The levels in a conscious action

Level 4: Neurons and synapses:

spike trains, activation thresholds,



Neuron:
Dendrites, nuclei,
Axons, synapses

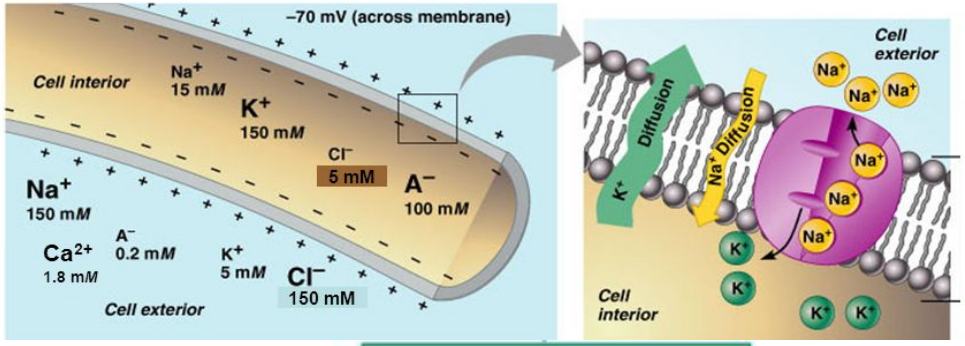
Synapse is a
Logic gate:

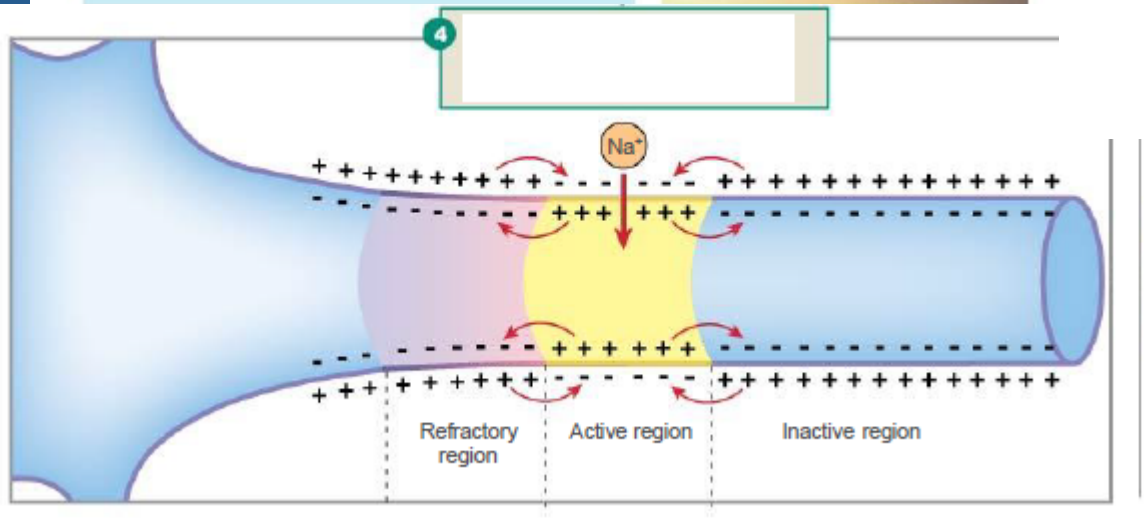
IF SUM > S THEN FIRE

Level 5: Electron and ionic flows

Biological Currents & Resting Potential (V_r)

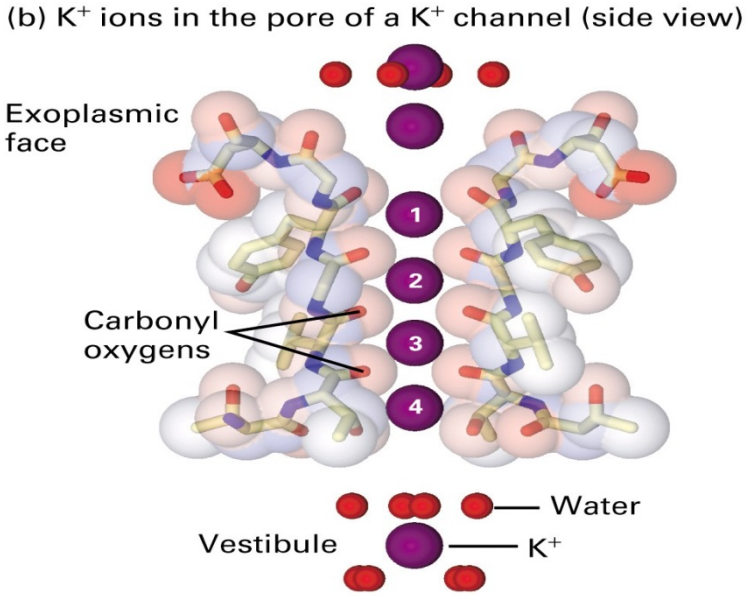
- Flow of ions rather than electrons
- Generated by different [Na^+], [K^+], [Cl^-], [anionic proteins] and charged phospholipids
- Ion gradients
  - Differential permeability to Na^+ and K^+
  - Sodium-potassium pump





Axon of a neuron

Ion channels

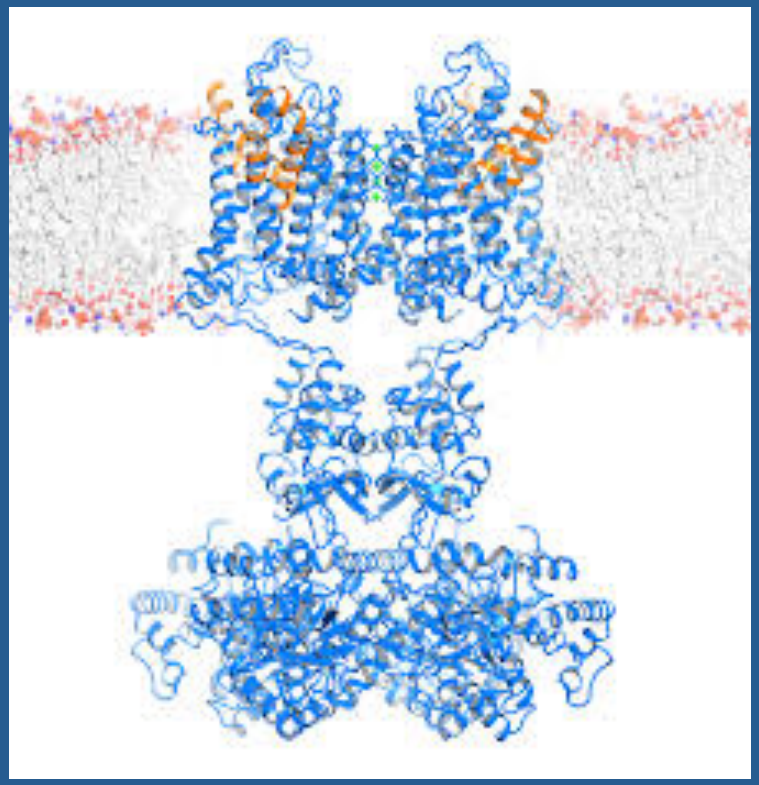


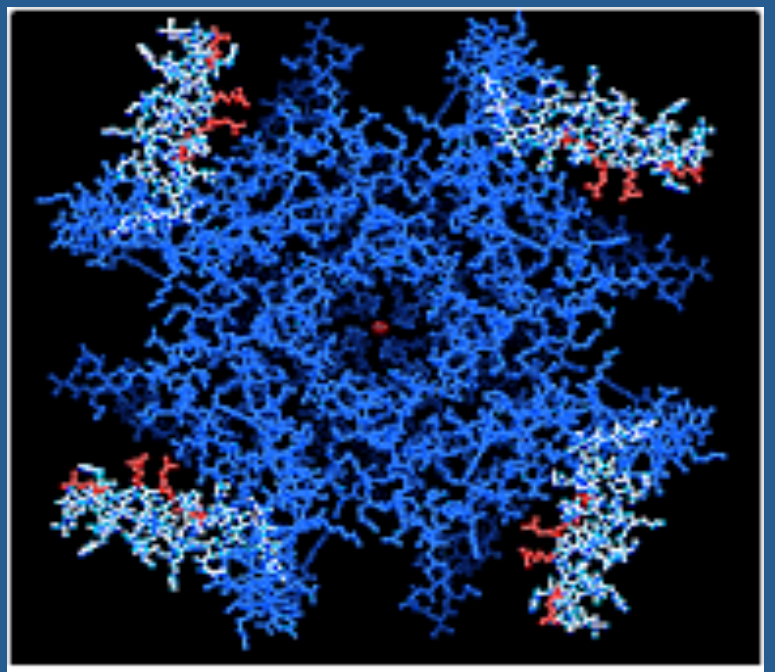
Maxwell's equations!
Plus Newton's laws of motion.

The levels in a conscious action

Basis: Bio-Molecules

Voltage gated ion channels (proteins)





An overhead view of a voltage-dependent potassium ion channel shows four red-tipped "paddles" that open and close in response to positive and negative charges. This structure, discovered by Rockefeller scientists, shows for the first time the molecular mechanism by which potassium ions are allowed in and out of living cells during a nerve or muscle impulse.

Molecular basis of “IF … THEN … “ logic

Biomolecules perform logical operations

Ion channels implement logical operations:

If voltage $V > V_0$ then let ions flow, else not (3)

- Underlies Hodgkin-Huxley equations and hence neural spikes and higher level brain logical operations

- Cannot possibly have arisen by chance: have to have been selected for
- Hence have come into being through the top-down process of adaptive selection

➔ Biomolecules in networks can be used to make logic gates and so build up higher level logical structures

Mathematical model

Potassium current

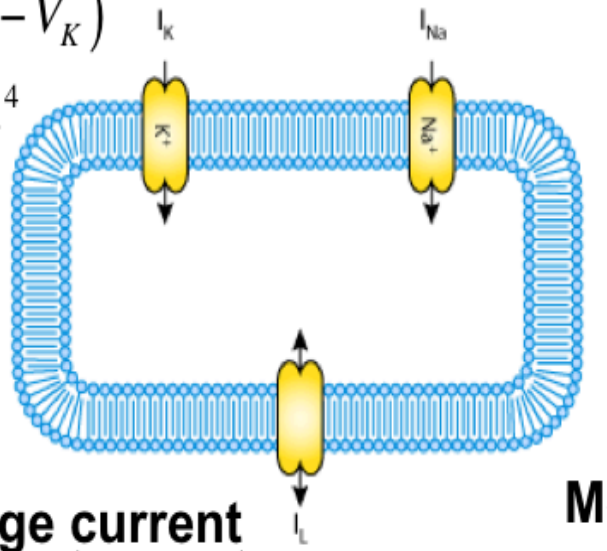
$$I_K = g_K\left(V - V_K\right)$$

$$g_K = g_{K_{max}}\, n^4$$

Sodium current

$$I_{Na} = g_{Na}\left(V - V_{Na}\right)$$

$$g_{Na} = g_{Na_{max}}\, m^3 h$$



Gates (n,m,h)

$$\frac{dX}{dt} = \alpha_X\left(1 - X\right) - \beta_X X$$

Leakage current

$$I_{leak} = g_{leak_{max}}\left(V - V_{leak}\right)$$

Membrane potential

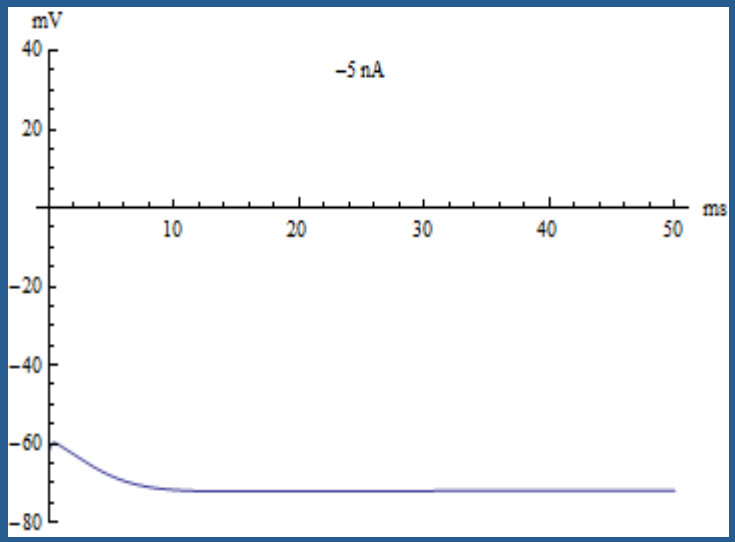
$$\frac{dV}{dt} = \frac{I_{stim} - \left(I_K + I_{Na} + I_{leak}\right)}{C_m}$$

Hodgkin-Huxley equations

Hodgkin-Huxley equations

As a consequence action potentials flow along axons

Enabling spike trains to carry signals between neurons



These get integrated in complex ways to create thoughts
- Such as deciding to bake a cake!

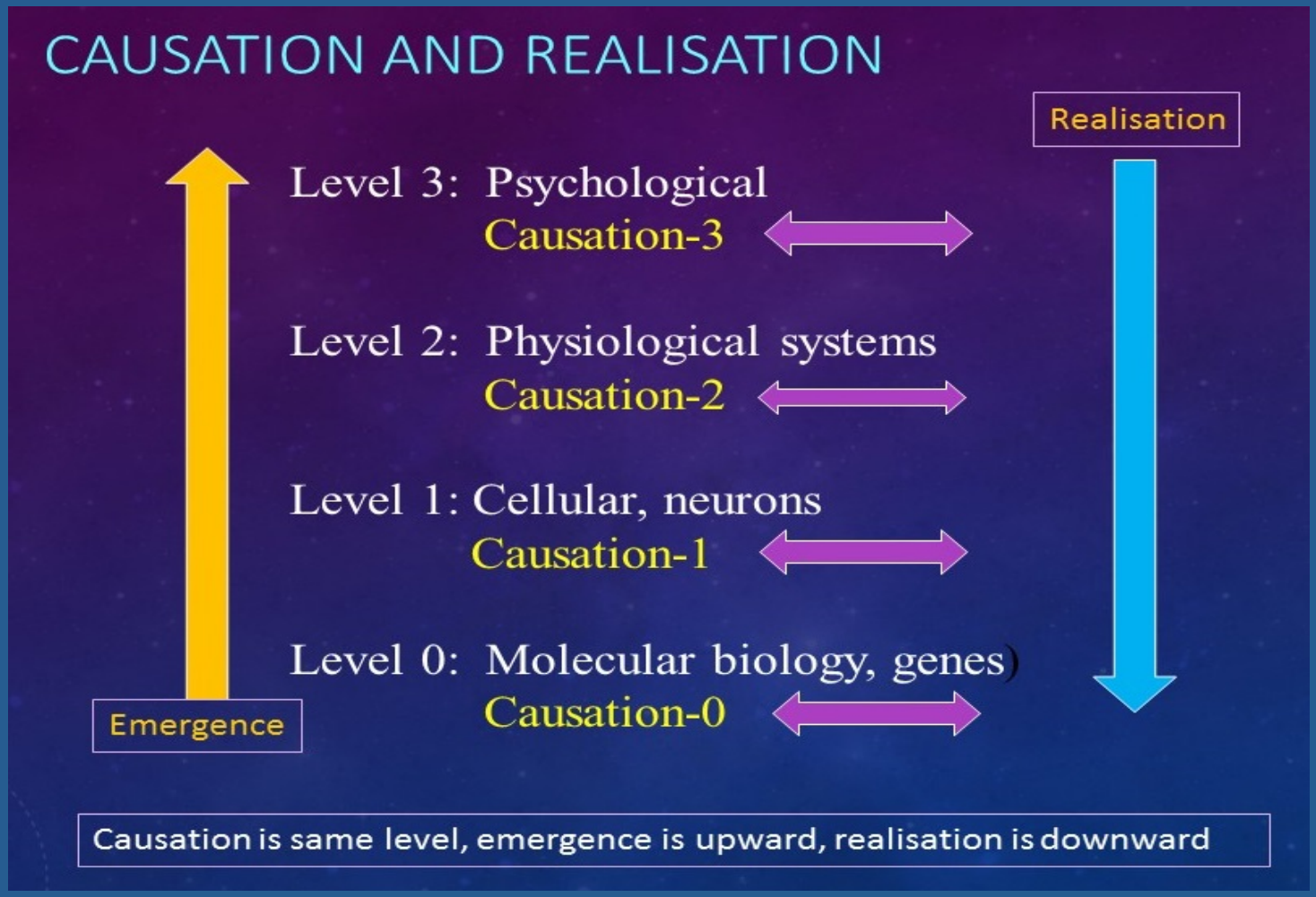
6. Conclusion

- The key link between physics and life is provided by bio-molecules, such as voltage gated ion channels.

- Through their structure they enable logic to emerge from the underlying physical laws, and for example underlie information processing in the brain via action potential spike trains governed by the Hodgkin-Huxley equations.

- They can exist because of the nature of possibility spaces for protein structures shaped by the underlying physics (as described by Andreas Wagner in his book *Arrival of the Fittest)*,
- but can only have come into being via the contextually dependent processes of natural selection, which selects them for their biological function.

Causation and Realisation



All levels are equally real. Causation takes place at each level, emergence is bottom up, and realisation is top-down. Multiple lower level realisability is possible for each higher level function.

Emergence

- Real emergence takes place, with higher levels having genuine causal powers and information processing capacities at each level
- This is enabled by bottom-up emergence in conjunction with top-down realisation on evolutionary, developmental, and functional timescales
- What is life? Inter alia, a system that can logically handle information at all levels at and above the macromolecular scale

References:

How Can Physics Underlie the Mind? Top-Down Causation in the Human Context George Ellis

Dance to the Tune of Life: Biological Relativity Denis Noble

What is the role of chance?

The occurrence of chance does not mean the outcome is random:

Rather, it provides the basis for selection of outcomes on the basis of higher level selection criteria, thus creating order out of disorder (Principle 6).

Indeed, microbiology thrives on randomness (Hoffmann 2012) as does brain function (Glimcher 2005, Rolls and Deco 2010).

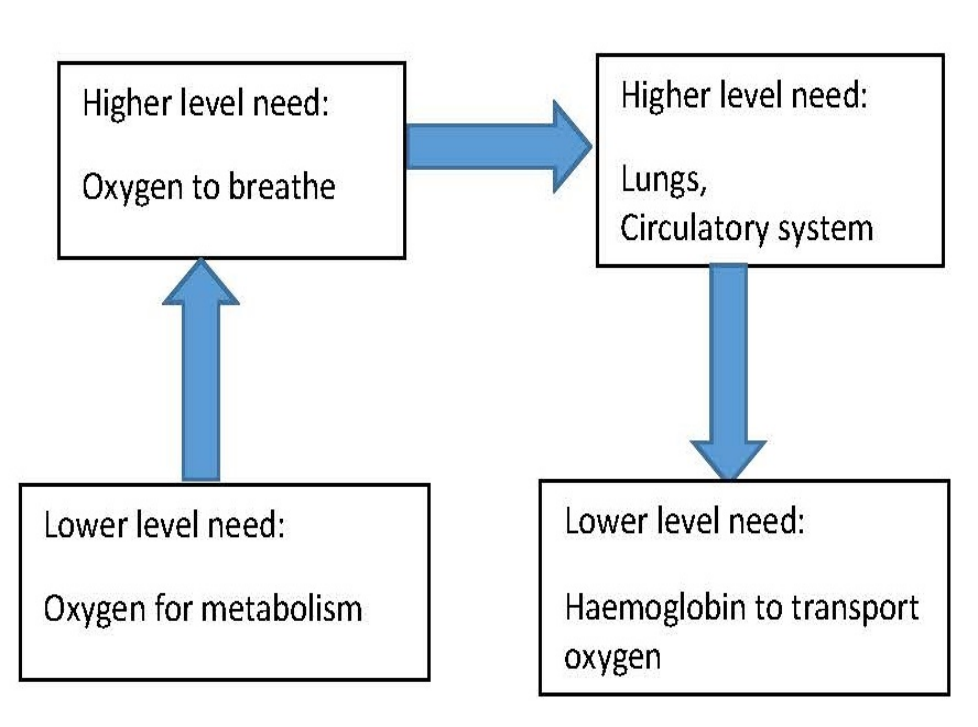
Statistical randomness between levels provides the material on which selection processes can operate. Quantum uncertainty might also play a role.

What decides what happens?

- The logic of the higher levels choses what will happen.
- The logic of the lower levels carry out that higher logic.
- Thus the higher levels have greater causal power.
- Adaptation takes place at all levels and timescales

Adaptive selection is doubly a top down process (environmental effects, choice of selection criteria S(X:C)) and underlies origin of information in both the logical and the implementation hierarchies

Multiple levels and the circulatory systems



There are lower level and higher level needs that must be satisfied simultaneously (Aristotle's four kinds of causation)

Strong emergence

Principle 7: Strong Emergence

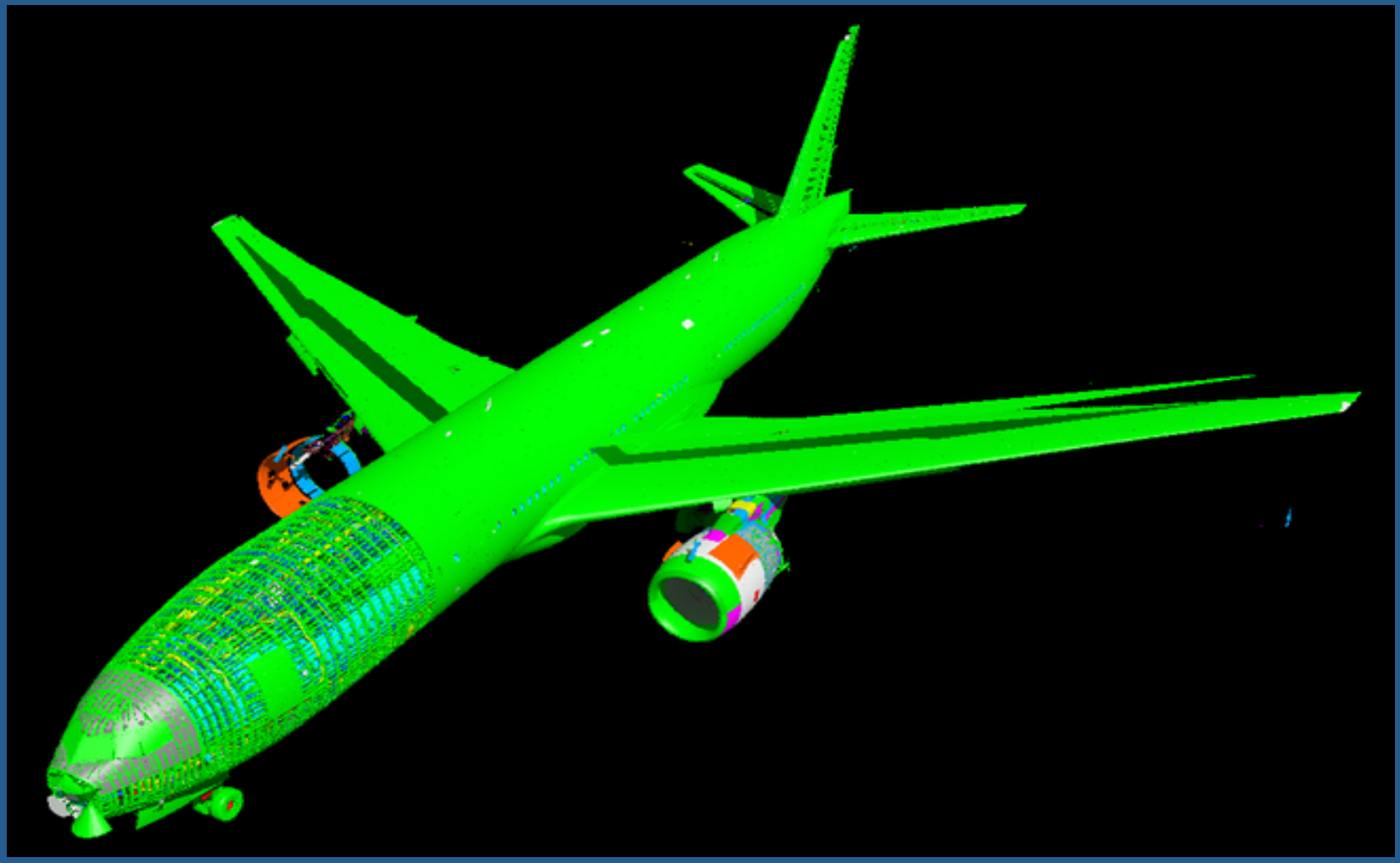
- *Strong Emergence takes place, with genuine causal powers coming into being at each higher level of an implementation hierarchy,*
- *allowing the logical processes appropriate to that level to occur independent of the lower level implementing medium.*
- *Logical outcomes occur based on the logic and information at each level.*

Causal effect of thoughts in the world

Aircraft Design: Plans for a Jumbo Jet aircraft result in billions of atoms being deployed to create the aircraft in accordance with those plans (intelligent to down causation). This is a non-trivial example: it costs a great deal of money to employ experts in aerodynamics, structures, materials, fuels, lubrication, controls, etc. to design and then to manufacture the aircraft in accordance with those plans

The plan itself is not equivalent to any single person's brain state: it is an abstract hierarchically structured equivalence class of representations (spoken, drawn, in computers, in brains, etc.) that together comprise the design.

It is clearly causally effective (the aircraft would not exist without it). It could not occur without language and mathematics, as well as the social systems in which it is embodied.

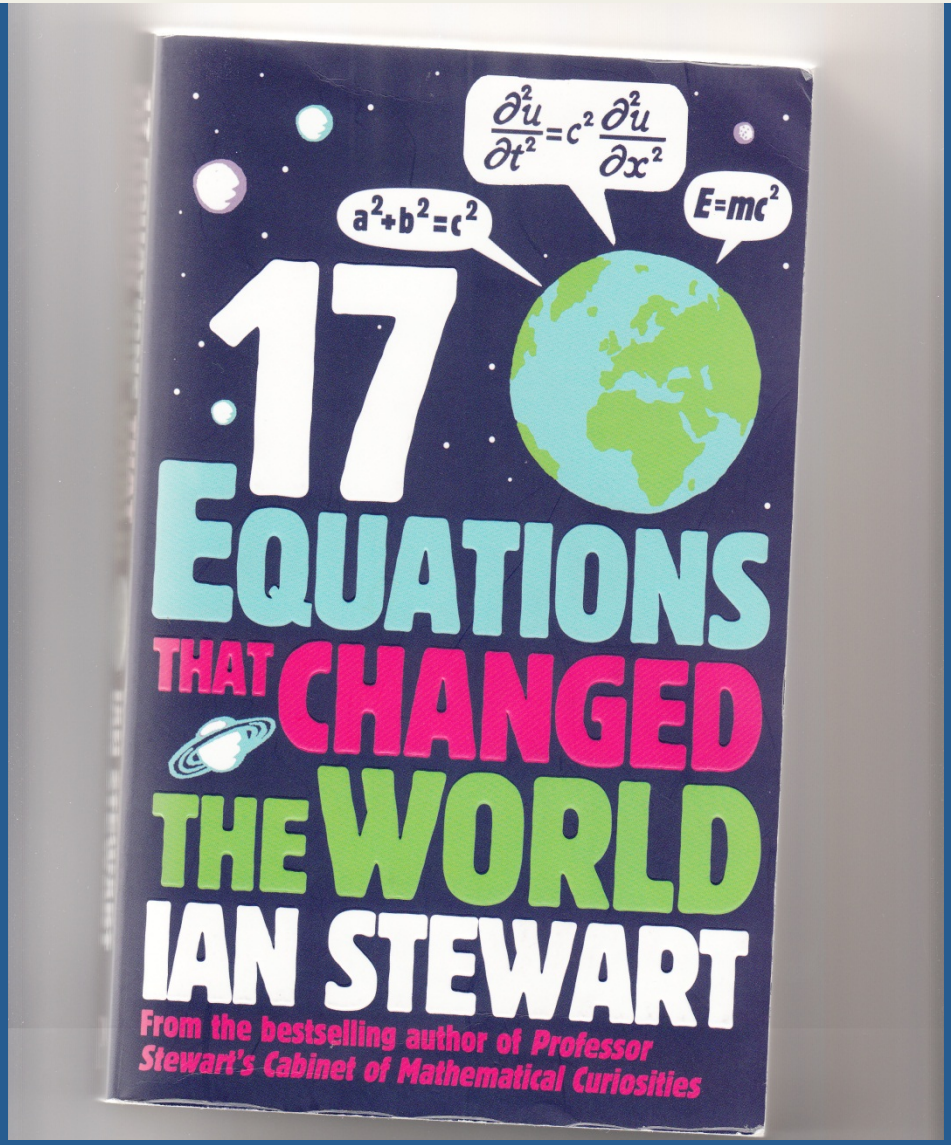


The abstract concept: Interactive Ray Tracing of Large Models Using Voxel Hierarchies Attila T. Áfra (Boeing 777)

Causal power of thoughts:
The physical outcome

Top down action from the mind to the levels of materials and molecules

This is enabled by the power of equations we have articulated in our minds, used in engineering design



Physics Theories: Maxwell's *equations* of electromagnetism (an abstract entity, described by Maxwell's equations) led to the development of radio, cell phones, TV, and so on. It is shown to be true by experiments and by its technological outcomes.

Maxwell's theory is not the same as any single person's brain state. It can be represented in many ways and formalisms

The abstract theory has altered physical configurations in the real world, and hence is causally effective.

It is an irreducible higher level causal factor (it cannot be derived by coarse-graining any lower level variables)

Non physical entities have enormous causal power

Physics Theories: Maxwell's *equations* of electromagnetism (an abstract entity, described by Maxwell's equations) led to the development of radio, cell phones, TV, and so on. It is shown to be true by experiments and by its technological outcomes.

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The abstract … real world, and hence is causal …

It is an irred… …ived by coarse-graining any lowe…

Non physica…

$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

The key analytic idea

In all cases, the key idea is that of functional equivalence classes: each equivalence class is a set of lower level states all that correspond to the same higher level state

- When you coarse grain, all of these lower level states correspond to the same higher level state
-Entropy is a measure of how many lower level states correspond to a specific higher level state (Penrose)

- These are what get selected for in when adaptation takes place

- Whenever you can identify existence of such equivalence classes, that is an indication that top-down causation is taking place

-**Multiple realisation as a key feature** It is the equivalence class at the lower level that realises a higher level variable, that has the real causal power.

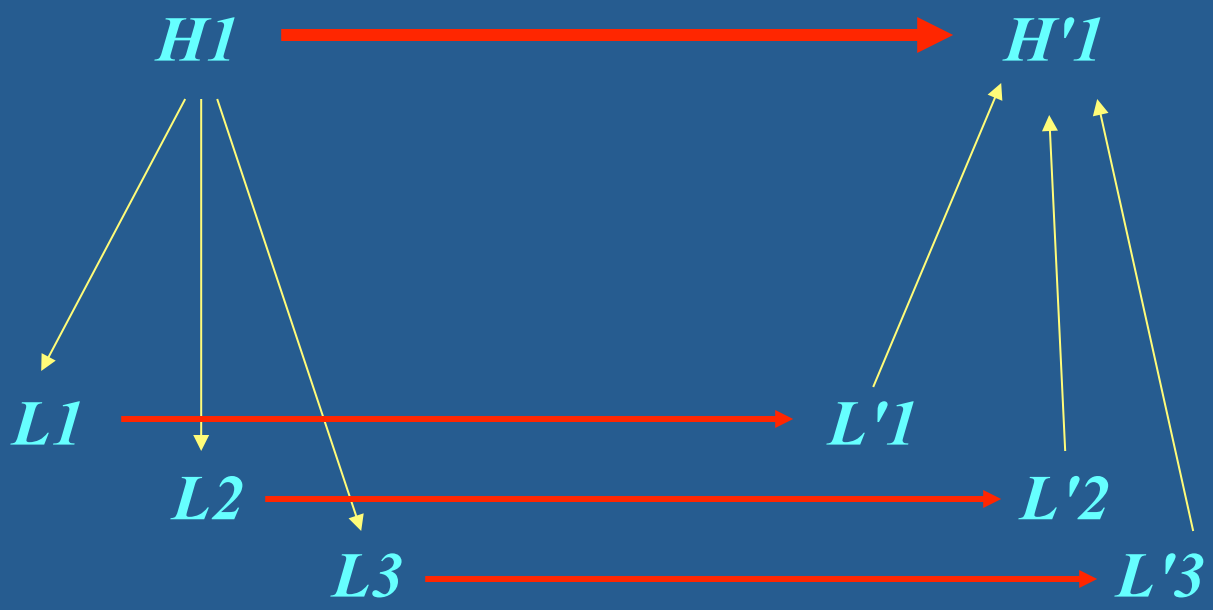
Multiple realisation and equivalence classes

A key feature of emergent complexity is that any specific higher level structure or function can be realised in many many ways at each lower level.

Equivalence classes of lower level entitites correspond to the higher level entity that is the rea causal agent.

Reliable emergent higher level behaviour

Set initial higher level state: what transpires?



The lower level dynamics lead to coherent higher same-level dynamics when the lower level dynamics acting on all the different lower level states corresponding to a single higher level state, give new lower level states corresponding to the same higher level state.
Examples: gas laws; entropy [Penrose].

Multiple realisability and natural kinds

Take any folk-psychological (FP) law, say,

$$FP1 \rightarrow FP2 . \qquad (A)$$

The causal relation is described in the notation of an 'if, then' statement. The following would be an example of a commonly employed FP law:

For any person P, if P desires Q and believes that doing X will achieve Q, then P will do X, *ceteris paribus*.

What happens if we try to describe this at a lower level?

The problem is that FP1 and FP2 are multiply realizable at lower levels. Thus, a bridge law between levels will look something like this:

FP1 = B1 or B2 or B3 or B4 . . . ,
FP2 = B20 or B30 or B40 . . . ,

resulting in the following reduced statement:

{B1 or B2 or B3 or B4 . . .} −⟶ {B30 or B30 or B40 . . . } (B)

There are two problems:

- Neither the antecedent nor the consequent describe a biological type.
- The sentence described is not a law of biology.

The real causal level is at the higher level

Network motifs in the transcriptional regulation network of *Escherichia coli*

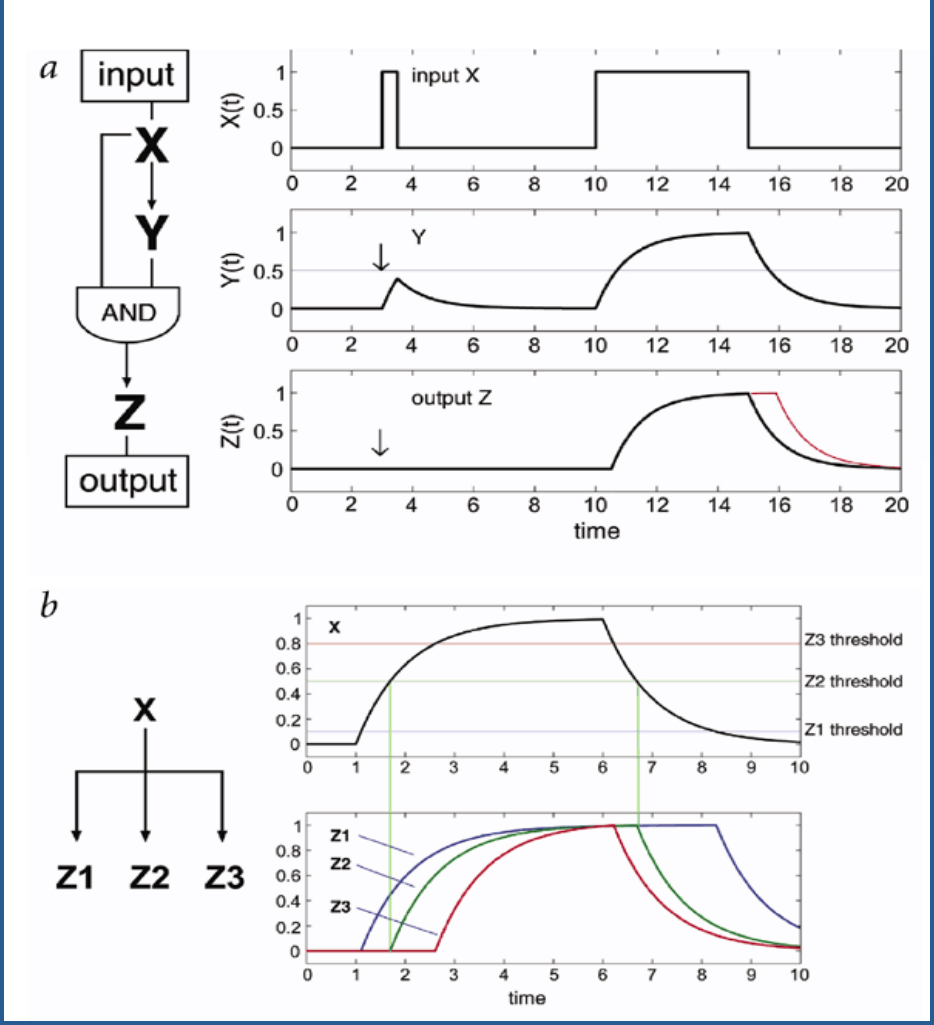
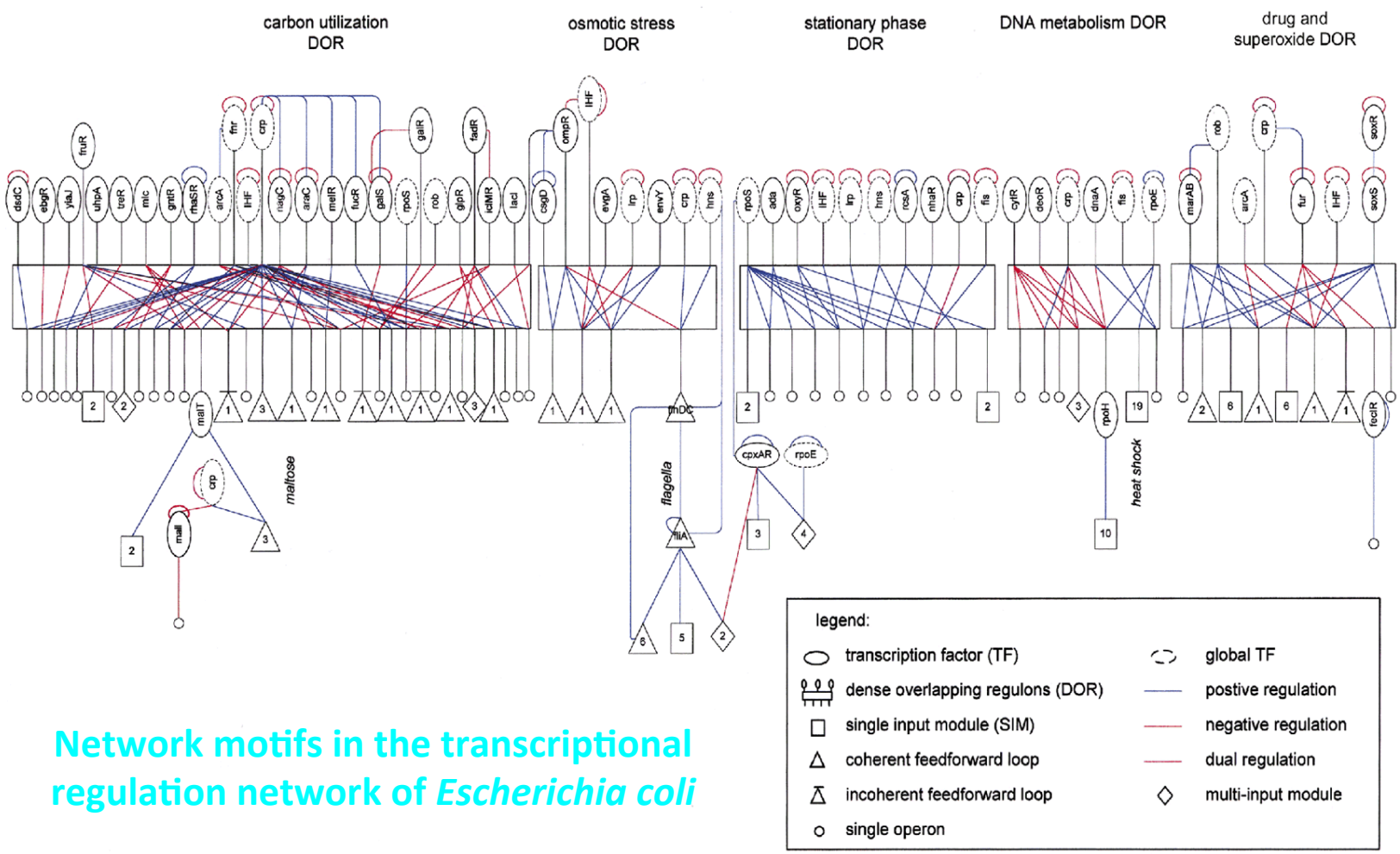


Fig. 2 ***a***, Consider a coherent feedforward loop circuit with an 'AND gate'– like control of the output operon Z.

This circuit can reject rapid variations in the activity of the input X, and respond only to persistent activation profiles.

b, Dynamics of the SIM motif. This motif can show a temporal program of expression according to a hierarchy of activation thresholds of the genes.

When the activity of X, the master activator, rises and falls with time, the genes with the lowest threshold are activated earliest and deactivated latest.



Network motifs in the transcriptional regulation network of *Escherichia coli*

Part of the network of transcriptional interactions in the *E. coli* data set, represented using network motifs. Nodes represent operons, and lines represent transcriptional regulation, directed so that the regulating transcription factor is above the regulated operons.

What about supervenience?

Suppose one could reproduce in every detail the structure of a computer or brain, and its current state of excitation. Would the identical higher level behaviour/effects emerge?

- Yes: maybe. So the higher level behaviour is determined in a bottom up way by the lower level, for example the brain works out the effects of Maxwell's equations in a bottom up way. There is thus no need for top down effects to occur; this is the argument from supervenience (Sean)

- But what it omits is that you can't get to that initial state in a purely bottom up way - the brain or computer can't self-assemble. How did the electrons in our cortex know about Maxwell's equations? - they exist in a context of neural connections that over time have been taught about those equations through a social process of education, based in the fact that mathematicians discovered at the mental level the nature of the underlying mathematics through the pattern recognition properties of the neural nets in the cortex, and Maxwell then realised they accurately described the nature of electromagnetic interactions.

What about the causal completeness of physics?

A claim often made is that emergence of causally effective higher level variables and processes is not possible, because the lower level physics is causally closed and determines what happens at all higher levels.

But lower level physics is not causally complete! Philosophers and many physicists seem not to have taken on board the implications of the quantum revolution of last century). Physics is not causally closed, because of quantum uncertainty.

And it cannot be closed, because information has come into being over time that was not there at the start of the universe . This proves conclusively that causal closure through physical processes alone cannot be true.

Information generation

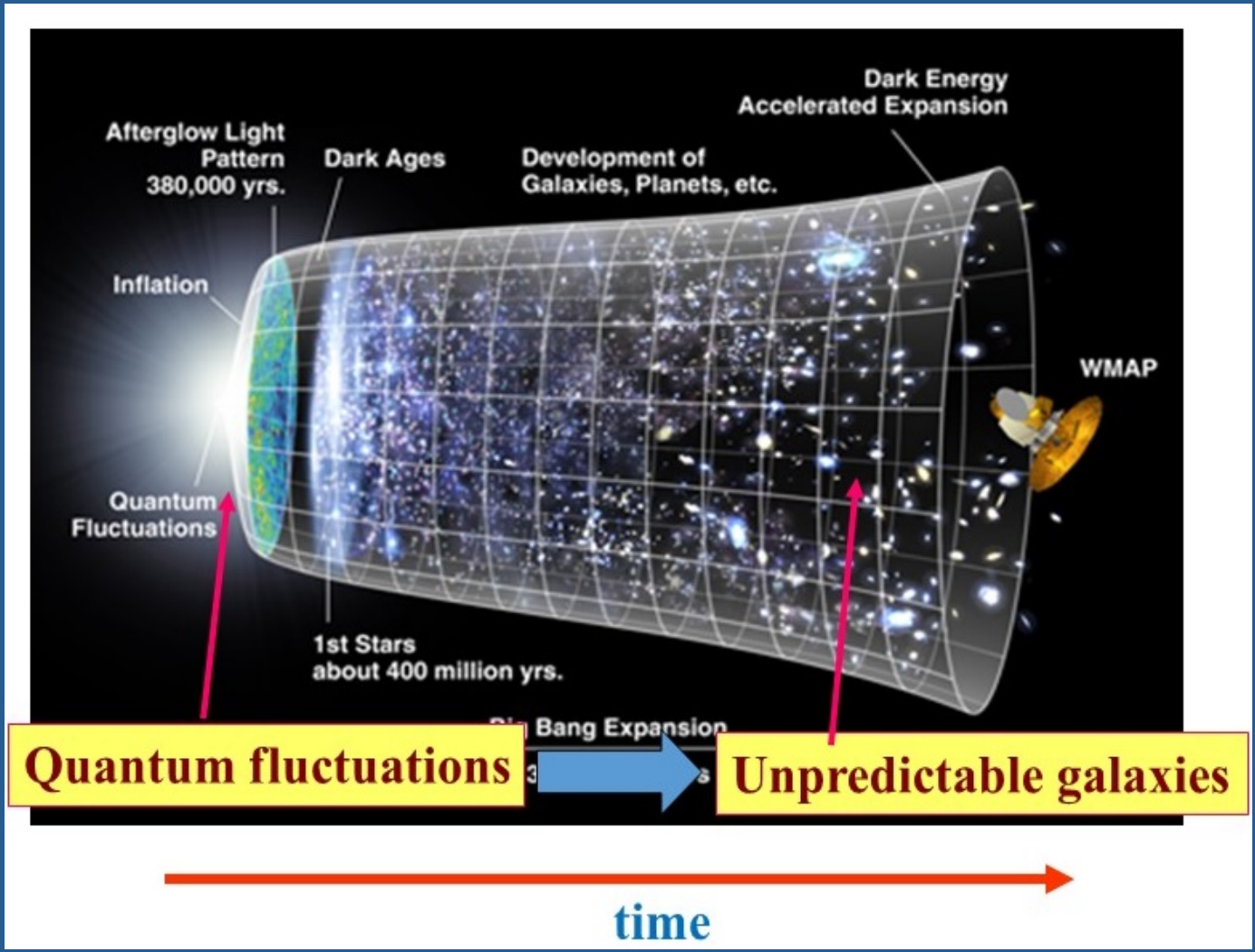
Principle 6: Information is generated over time

- *The needed information for emergence both of specific forms of life, and of intelligent outcomes such as the text of Einstein's 1915 General Relativity paper, was not present in the very early universe.*

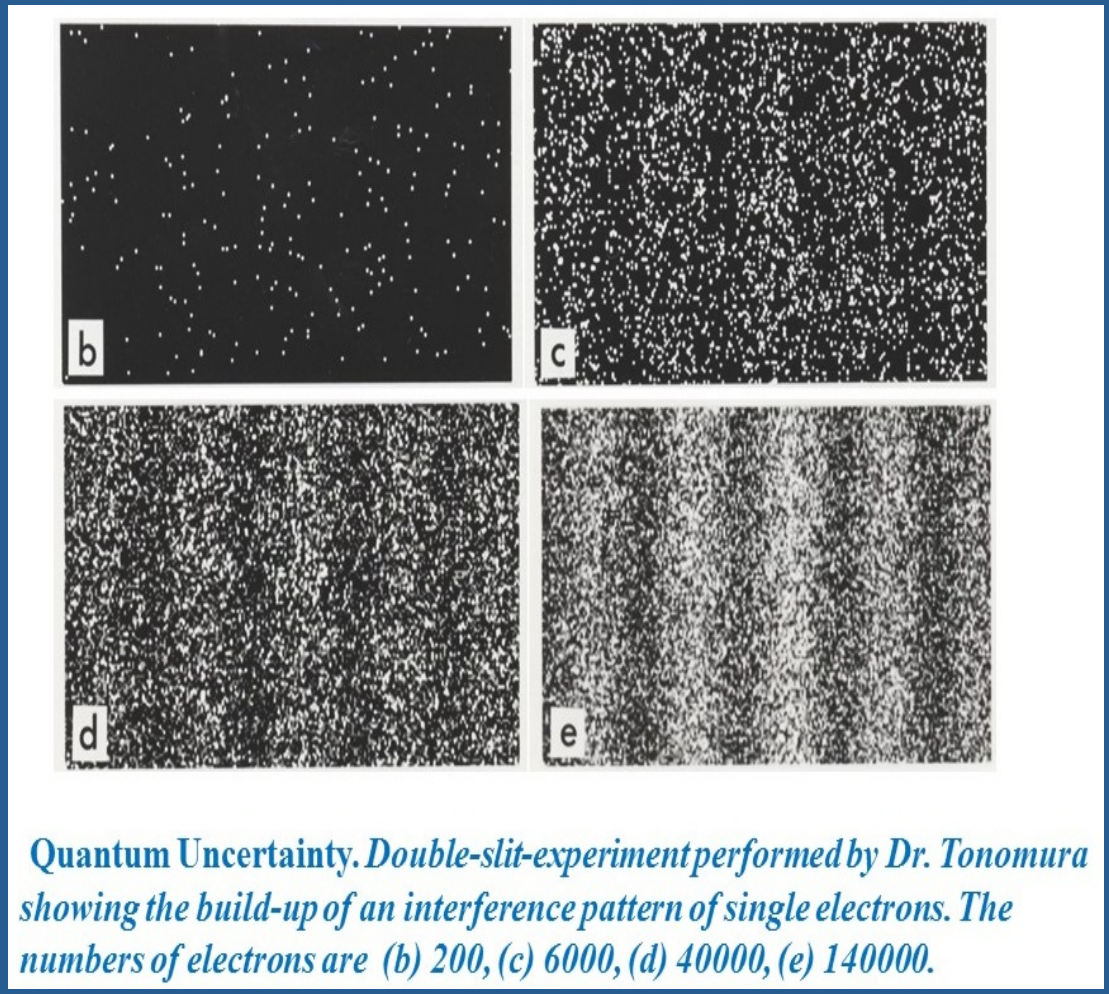
- *This is* inter alia *because of quantum and statistical uncertainty at the micro level, which affects macro outcomes.*

- *The information needed to determine specific such outcomes is not written there: it has to have come into existence at later times.*

The cosmic context



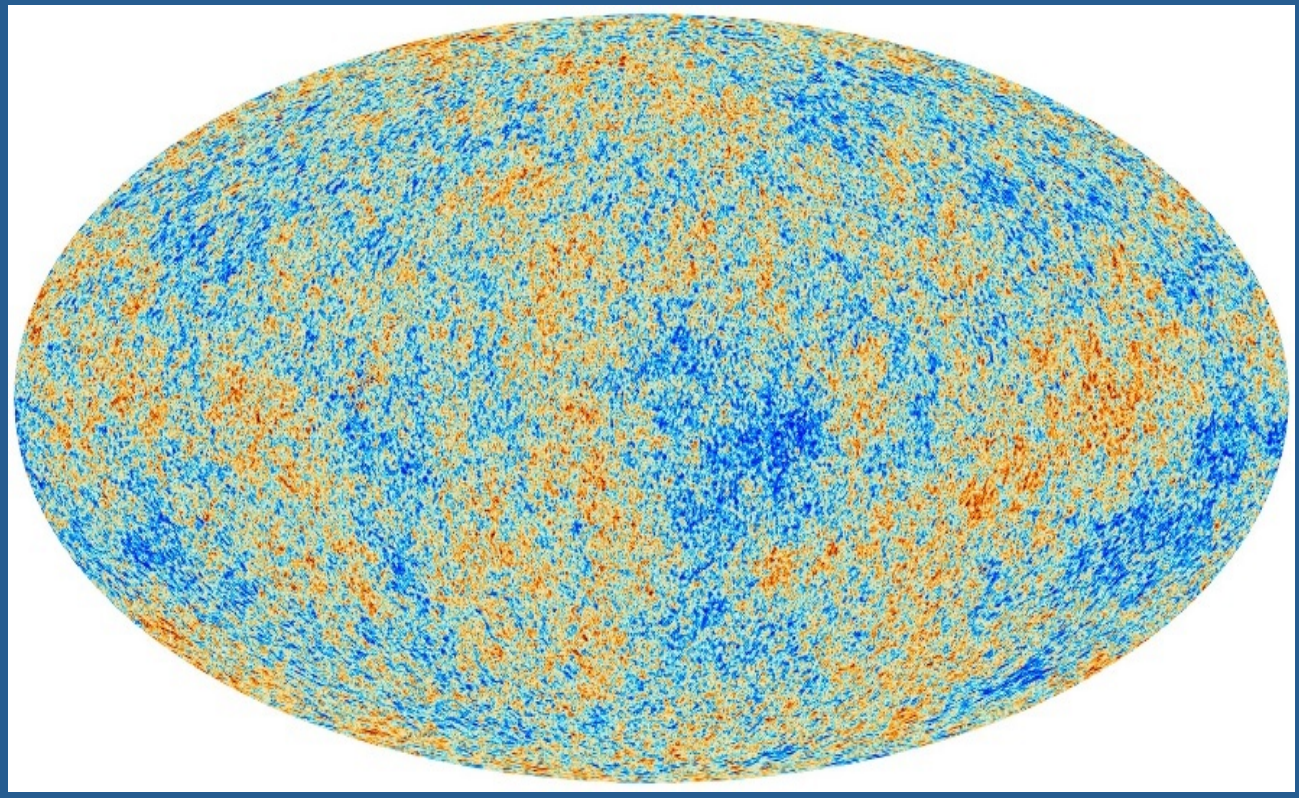
Quantum uncertainty



Quantum Uncertainty. *Double-slit-experiment performed by Dr. Tonomura showing the build-up of an interference pattern of single electrons. The numbers of electrons are (b) 200, (c) 6000, (d) 40000, (e) 140000.*

Quantum Uncertainty. *Two-slit experiment demonstrating the fact that we cannot even in principle predict the specific outcomes that will occur at the micro level. W e can however predict the statistics of the outcome.*

Modulated Random Gaussian fluctuations



The kind of initial data from which the present day universe developed, as imaged by the Planck Satellite. No transfer function can work from this data to give present day thoughts. No demiurge has written human thoughts there