Top Down Causation and the Emergence of Complexity

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SAIP Conference 2011

- *Nature* 435: 743 (9 June 2005).
- *Foundations of Physics* (Apr 2006), 1–36
- *Transactions Roy Soc SA 63:* 69-84 (2008)*:*

http://www.mth.uct.ac.za/~ellis/Top-down%20Ellis.pdf

- *Journ Roy Soc (London) Interface Focus* (2011)

This talk:

1: Causation in complex systems

2: Occurrence of Bottom-up and top-down action

3: Five different kinds of top-down action
- *examples from physics and biology*

4: Causal closure and physics

5: Where does top down causation occur in physics?

6: The nature of causality

7: Completeness of physics?

1: Causation in complex systems

The nature of causation is a core issue for science, which can be regarded as the move from a demon-centered world to a world based on reliable cause and effect, tested by experimental verification

Physics is the basic science, characterized by mathematical descriptions that allow predictions of physical behavior to astonishing accuracy and underlies the other sciences.

The key question is whether other forms of causation such as those investigated in biology, psychology, and the social sciences are genuinely effective, or are they rather all epiphenomena grounded in purely physical causation?

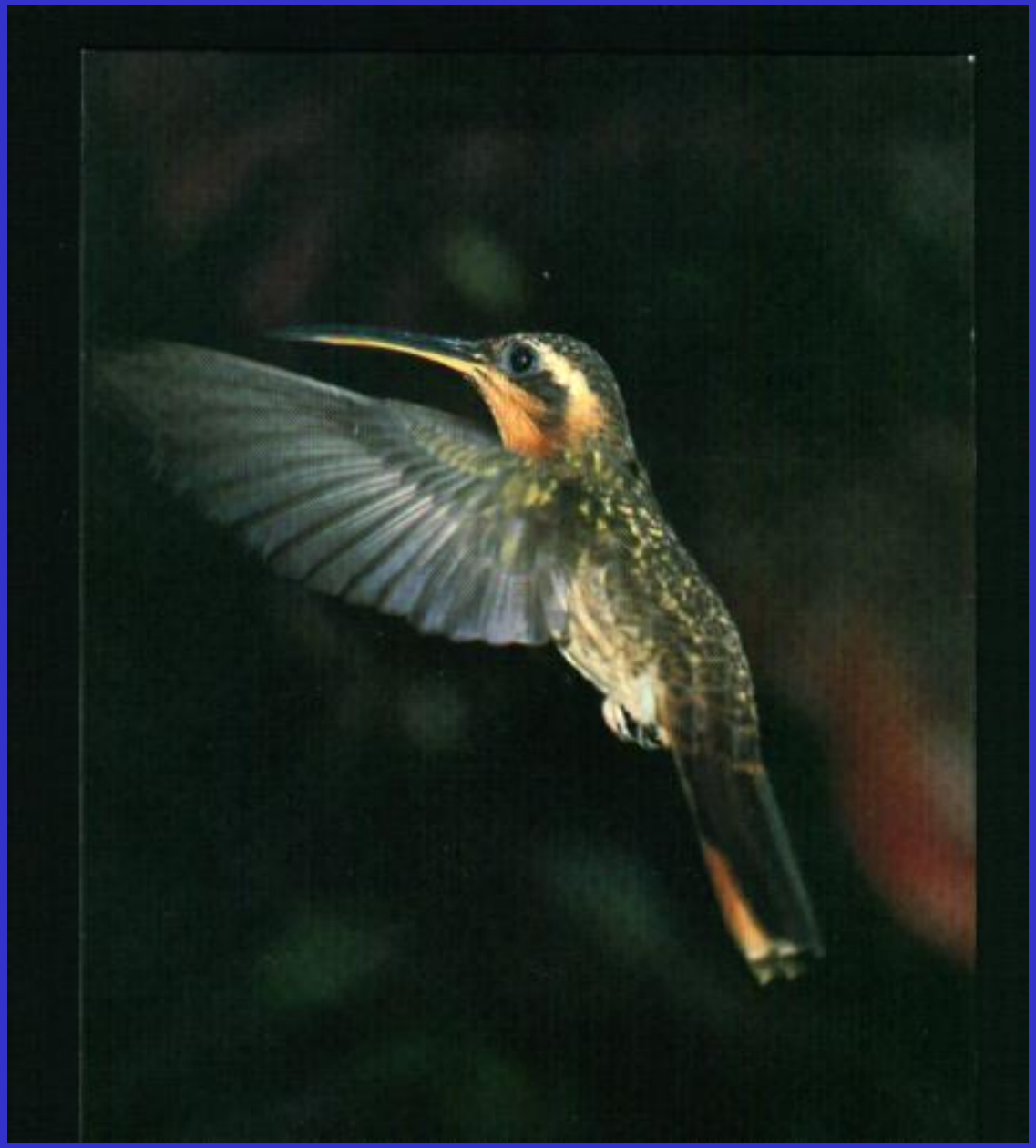
The nature of causation

I will claim here that *there are other forms of causation than those encompassed by physics and physical chemistry,* described quite well by Aristotle's four types of causes .

A full scientific view of the world must recognise this fact, or else it will ignore important aspects of causation in the real world, and so will give a causally incomplete view of things

The key idea I will pursue is that as well as bottom-up causation, top-down causation takes place in these structures, due in particular to the crucial role of context in determining the outcomes of lower level causation.

Physical outcomes are context dependent!



Complexity and Structure

Physics underlies all complexity, including life. How does it work?

True complexity, with the emergence of higher levels of order and meaning, occurs in *modular hierarchical structures*
- because this is the only viable ways of building up real complexity on the basis of the underlying physics.

A hierarchy, *with many layers of structure built upon each other,* represents a decomposition of the problem into constituent parts and into processes to handle those constituent parts,
- each part requiring less data and processing, and more restricted operations, than the problem as a whole.

The levels of a hierarchy represent *different levels of abstraction*, each built upon the other, and understandable by itself

The Hierarchy of Structure: 1

Sociology/Economics/Politics

Psychology

Botany/Zoology/Physiology

Cell biology

Biochemistry

Chemistry

Atomic Physics

Particle physics

2: Bottom-up and Top-down action

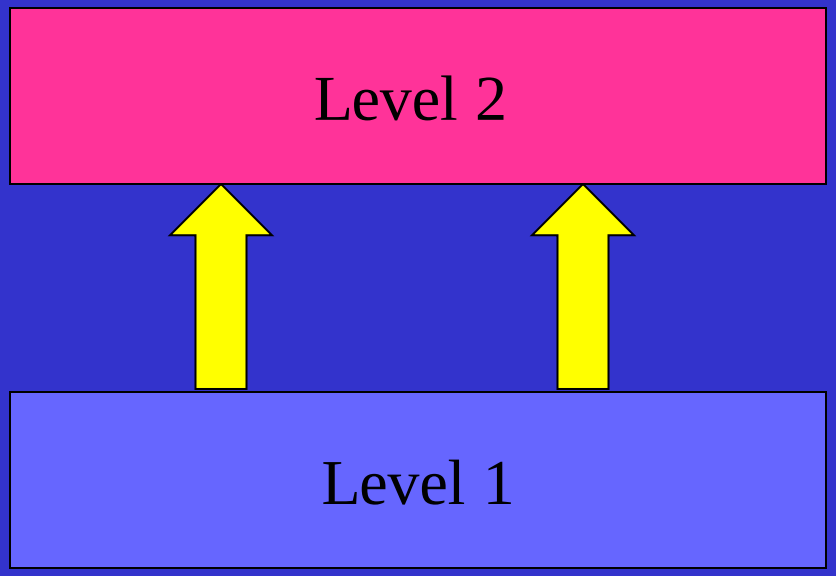
Bottom-up action is when what happens at the higher levels is controlled by what happens at the lower levels

- *micro-physics underlies macro physics, e.g. kinetic theory of gases, theory of solids (conduction, thermal capacity)*

- *physics underlies chemistry, e.g. nature of chemical bond*

- *physics and chemistry underlie the functioning of the brain*

- *individual human behaviour underlies the functioning of society*



Bottom-up causation alone:

Micro forces determine what happens at the higher levels

They are the foundation of higher level activity

Bottom-up and Top-down action

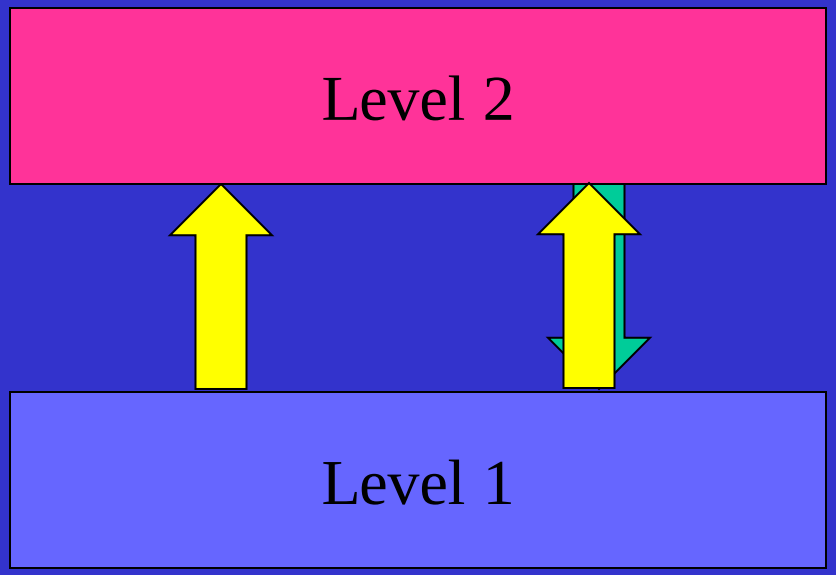
Top-down action is when the higher levels of the hierarchy causally effect what happens at the lower levels, in a coordinated way.

Boundary effects (linking the system to the environment) as well as structural relations in the system itself effect top-down action.

-enables higher levels to co-ordinate action at lower levels, by determining their context;

- *enables self-organisation of complex systems*
  hence enables true complexity to occur

- is prevalent in the real physical world and in biology, because no real physical or biological system is isolated



Bottom-up and top-down causation:

Additionally the higher levels control causal effects at the lower levels

3: Five different kinds of Top-down action

Five different classes of top-down causation will be identified and illustrated with real-world examples.

TDC1. Algorithmic top-down causation

TDC2. Top-down causation via non-adaptive information control

TDC3. Top-down causation via adaptive selection

TDC4. Top-down causation via adaptive information control

TDC5. Intelligent top-down causation

- the effect of the human mind on the physical world

TDC1: Algorithmic top-down causation

Algorithmic top-down causation occurs when high-level variables have causal power over lower level dynamics through system structuring,

- so that *the outcome depends uniquely on the higher level structural, boundary, and initial conditions*.

The lower level variables determine the outcome in an algorithmic way from the initial and boundary conditions as a consequence of the higher level structural relations

How do you show it is top down causation?
Change the environment: the result is different

Example 1: The synthesis of light elements in the early universe.

The amount of helium produced depends on the rate of change of temperature in the expanding universe, which is controlled by the gravitational equations and the average amount of matter in the universe. Thus quantities defined at the cosmological level control the products of detailed nuclear reactions at the micro level.

Example 2. Algorithmic computational procedures in a digital computer *that proceed on the basis of initial data only*: playing music, displaying pictures, data processing

Mathematics?

- Partial differential equations

- Dependence on boundary conditions

- Dynamical systems theory: ODEs

- phase planes, attractors

  Lyapunov 1947, Poincare 1957, Bellman 1953

- Computer Science:

- Programs and Algorithms, computability

TDC2: Top-down causation via non-adaptive information control

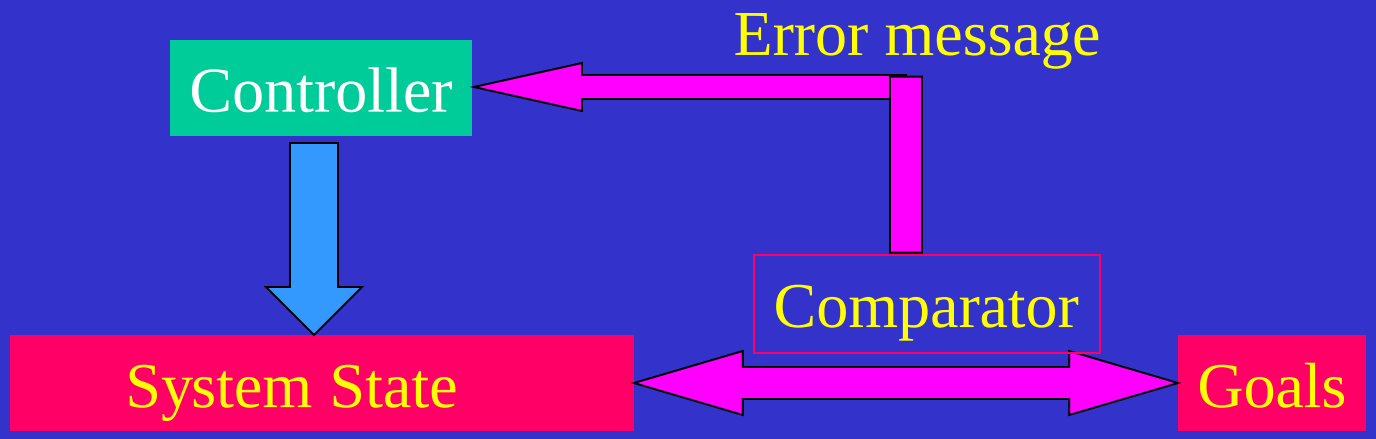
In non-adaptive information control,

- higher level entities influence lower level entities so as to attain specific fixed goals through the existence of feedback control loops,

- whereby information on the difference between the system actual state and desired state is used to lessen this discrepancy

Feedback control systems and information

Feedback control (*cybernetic systems: Norbert Wiener*)



Examples - the temperature of a shower
- the speed of a steam engine (James Watt)

This is the way information is causally effective

The role of goals in dynamics

The nature of causality is different when feedback control systems are guided by goals

Standard Physics

(physics, equations of state, initial conditions) → (outcomes)

(initial conditions) → (outcomes)

Feedback control systems

(physics, physical structure, goals) → (outcomes)

(goals) → (outcomes)

- ***The outcome of a feedback control system is determined by the goals rather than the initial data***

Top-down causation via non-adaptive information control

Homeostasis in the human body:

- Body temperature
- Blood Pressure
- Normal heart rate
- Transport across cell membranes

- each is governed by implicit goals, embodied in the physical structure of the body:

'the human body has literally thousands of control systems in it' [Guyton]

- They occur at all higher scales in the hierarchy

- They have been built in through the adaptive process of evolution and so embody images of environment

The role of goals and information

The series of goals in a feedback control system are causally effective

They embody information about the system's desired behaviour or responses – living systems are goal seeking ('*teleonomic*')

A complete causal description must necessarily take them into account. They exist as emergent properties of the system – they are not embodied in any component on its own.

How do you show it is top down causation?
- Change the goals, the outcome is different

Mathematics?

- Control systems theory

  J C Maxwell: 1868

  Nyquist 1932, Bode 1960

- *Feedback and control systems*

  DiStefano, Stubberud, Williams

- *Control theory and systems biology*

  Igleasias and Ingalls

TDC3. Top-down causation via adaptive selection

Adaptive processes take place when many entities interact and *variation takes place in the properties of these entities, followed by selection of preferred entities that are better suited to their environment or context*.

Higher level environments provide niches that are either favorable or unfavorable to particular kinds of lower level entities; those variations that are better suited to the niche are preserved and the others decay away.

A selection agent or selector accepts one of the states and rejects the rest on the basis of fitness criteria guiding adaptive selection. This selected state is then the current system state that forms the starting basis for the next round of selection

Top-down causation by adaptive selection: Darwinian evolution

Development of DNA codings (the particular sequence of bases in the DNA) through an evolutionary process which results in adaptation of an organism to its ecological niche.

This is a classical case of top down action from the environment to detailed biological microstructure - through the process of Darwinian adaptation, the environment (along with other causal factors) fixes the specific DNA coding.

There is no way you could ever predict this coding on the basis of biochemistry or microphysics alone. *You can't even ask the appropriate questions in their languages*.

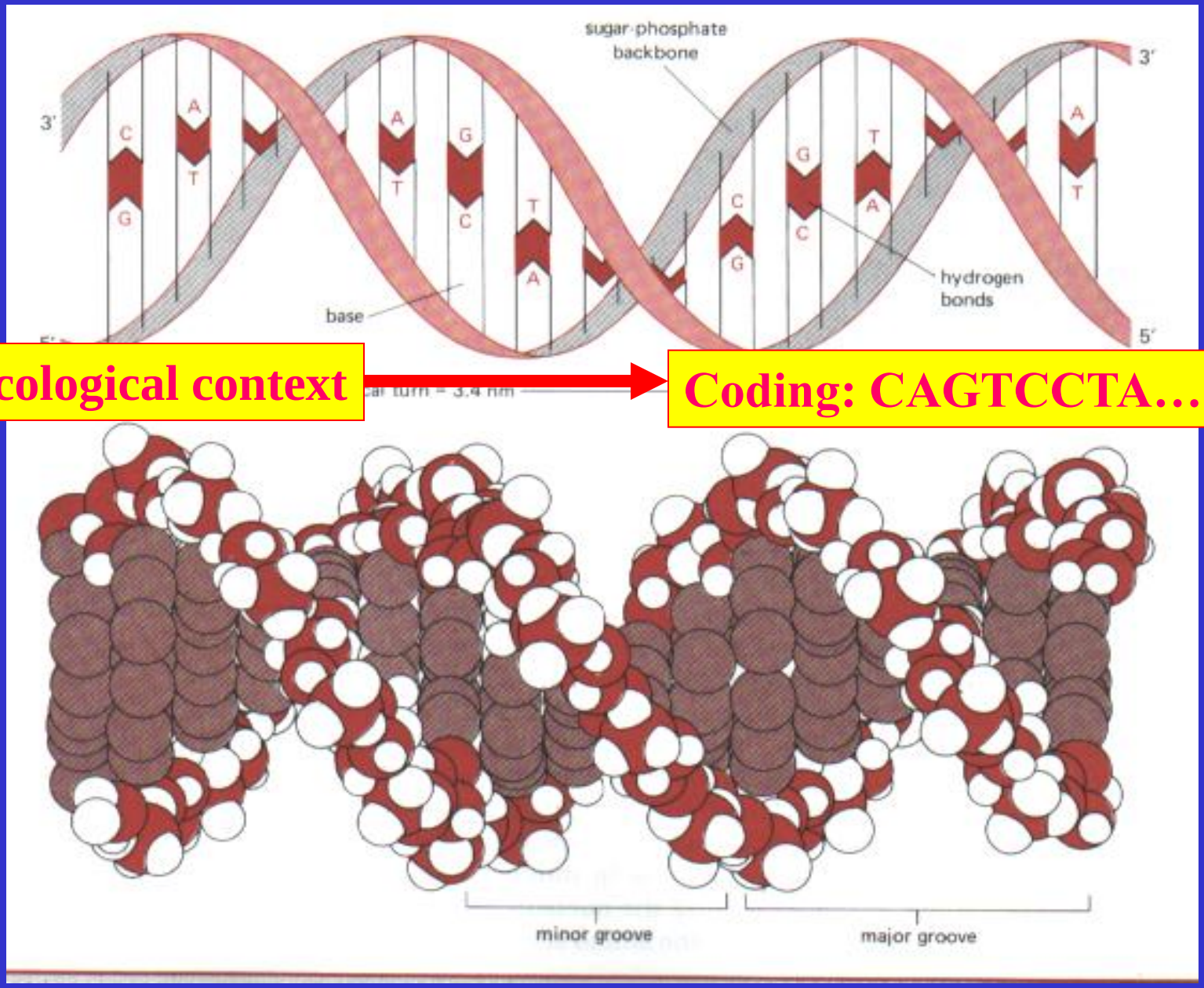
Environment

Animal

DNA sequence

How do you show it is top-down causation?

- Change the environment: the result is different



Ecological context → **Coding: CAGTCCTA…**

The DNA double helix with complementary base pairs

Mathematics/ formalisation?

Adaptation in Natural and Artificial systems
- Holland

Computers: *Neural Networks for Pattern Recognition*, Bishop

Genetic algorithms: *Introduction to Evolutionary Computing*, Eiben, Smith:

Population genetics - Gillespie

- Idea of space of possibilities: state space
- possibility landscape (biology)

TDC4. Top-down causation via adaptive information control

Adaptive information control takes place when there is *adaptive selection of goals in a feedback control system*,
- thus combining both feedback control and adaptive selection.

The goals of the feedback control system are irreducible higher level variables determining the outcome, but are not fixed as in the case of non-adaptive feedback control; they can be adaptively changed in response to experience and information received.

The overall process is guided by fitness criteria for selection of goals.

Top-down causation via adaptive information control

Associative learning in animals, such as Pavlovian conditioning:

- animal response to a stimulus such as a sound, which is taken as a sign of something else and causes physical reactions implemented by motor neurons (a dog salivates when you ring a bell)

The training is causally effective by top-down action from the brain to cells in muscles. The fitness criterion is avoidance of negative stimuli.

How do you demonstrate this top-down causation? - change the conditioning, and the response is different.

Mathematics?

- *Evolutionary game theory*

John Maynard Smith and George R. Price

- study the evolutionary dynamics in games is through replicator equations

- find Evolutionary Stable Strategies

- *Evolutionary dynamics: exploring the equations of life*, Martin A. Nowak

- perhaps

TDC5: Intelligent top-down causation

- The effect of the human mind on the physical world.

Intelligent top-down causation is the special case of feedback control with adaptive choice of goals where the selection of goals involves the use of symbolic representation to investigate the outcome of goal choices.

The key feature of this higher level of causation, is its use of language and abstract symbolism,

- extending to the quantitative and geometrical representations of mathematical and physical models

***Physics Theories*:** Maxwell's *theory* 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)

***Aircraft Design*: Plans for a Jumbo Jet aircraft** result in billions of atoms being deployed to create the aircraft in accordance with those plans.

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 not a physical thing but is clearly causally effective (the aircraft would not exist without it).


Boeing 747-400

The nature of goals

Conscious Goals in human activity:

- *our actions are governed by hierarchically structured goals at all structural levels in society*
- *these may be explicit or implicit, qualitative or quantitative*

- *they are not physical quantities*
- *they can be represented in many ways, so are effectively an equivalence class of representations*

Mathematics/Formalisation??

- Evolutionary game theory as a basis for social sciences

- Neuro-economics:

Decision, Uncertainty and the brain: Glimcher

- Decision making and Bayes theorem

- BUT beware!!
- Financial mathematics and the quants:
  The disaster of the Black-Scholes equation

Don’t confuse these equations with reality.
They are of limited use,
Human behaviour is not predictable

4: Causal closure and physics

The mind is based in brain operations; and these are based in the underlying physics

Claim some make: *Physics does not just constrain what happens, it uniquely determines what happens.*

If basic physics determines all, the situation is causally closed; there is no room for higher level influences.
- *Despite appearances, they are epi-phenomena .*

But: physics causes are not the only effective causes.
- Rather they form a vehicle for other kinds of causality to operate.

Causal openness for higher causes is there because

1: The functioning (according to the laws of physics) of the parts of given nature is determined by ***context***.

Higher level purposes can conscript physics to its ends by changing the operating context/altering context dependent constraints. Structure and boundary conditions crucially affect outcomes. This is an essential part of top-down and same-level action.

Example 1: a computer operated as music system or word processor.

Example 2: muscle cells being used in football or in playing music.

Causal openness for higher causes is there because

2: We do not just have invariantly functioning parts assembled in different ways and so operating in different contexts.

The nature of the parts – the way they function – is also affected by context in a top-down way. Indeed they are often adapted to their higher level function.

Example 1: hydrogen atom in water molecule

Example 2: free neutrons versus neutrons bound in a nucleus

Example 3: cells in the human body (through developmental biology)

Causal openness for higher causes is there because

3: Chance (statistics associated with coarse graining, random boundary conditions, quantum uncertainty) means physical outcome in biological systems is not uniquely determined by physical effects alone.

- *This provides the openness needed for adaptive selection processes to choose outcomes that satisfy higher level goals and values.*

This top-down mechanism may be far more prevalent than recognized up to now in the developmental and functional contexts as well as the evolutionary context.

Example 1: Adaptive immune system.

Example 2: Brain plasticity: Neural Darwinism **in the brain**

The Hierarchy of Structure: 2

Cosmology

Astronomy, Astrophysics

Earth Science

Geology

Materials science

Chemistry

Atomic Physics

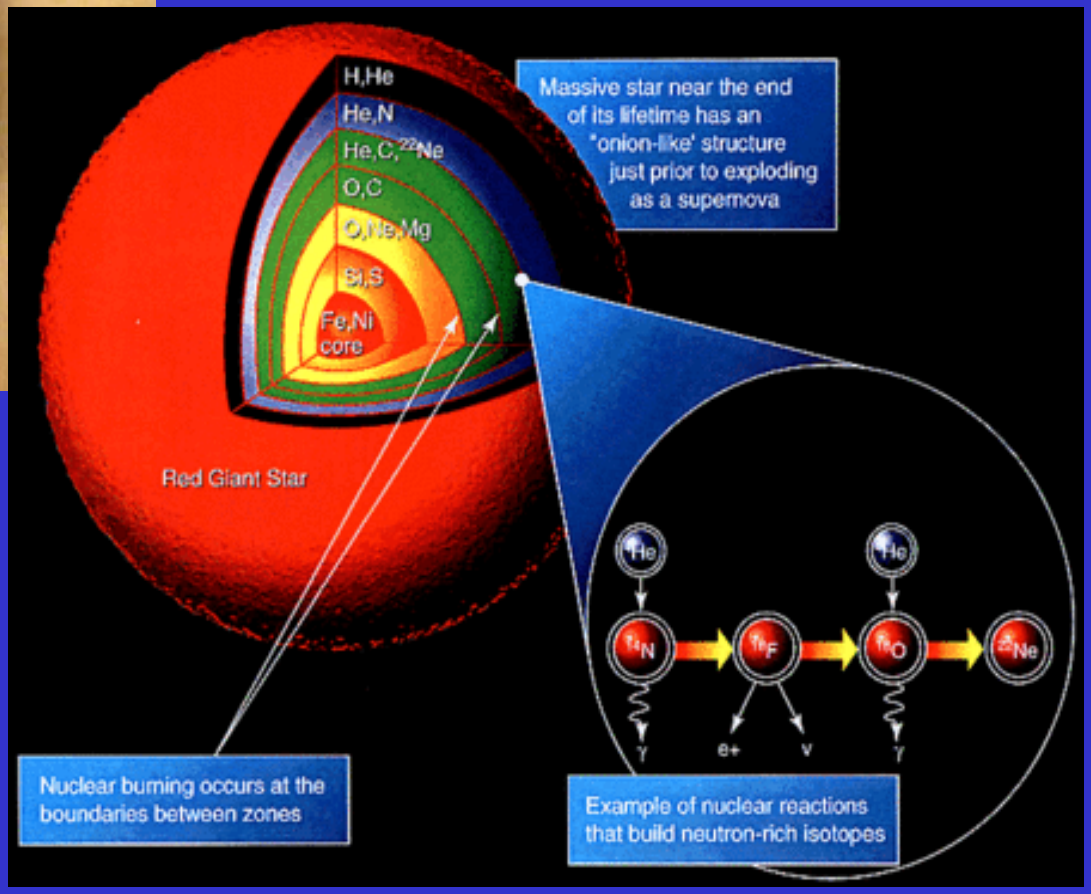
Particle physics

5 Where Does Top Down Causation occur in physics?

- TDC1: Algorithmic: various subcases

(1) Whenever the shape of a container determines local outcomes (as opposed to when it is irrelevant).

- Vibrations of a drum, sound waves in a musical instrument
- Rayleigh-Benard cells in a heated viscous medium
- Patterns formed by the reaction diffusion equation
- The physical interactions in the interior of a star


H,He
He,N
He,C,22Ne
O,C
O,Ne,Mg
Si,S
Fe,Ni core
Red Giant Star
Massive star near the end of its lifetime has an 'onion-like' structure just prior to exploding as a supernova
Nuclear burning occurs at the boundaries between zones
Example of nuclear reactions that build neutron-rich isotopes
4He
4He
14N
18F
18O
22Ne
γ
e+
ν
γ

Where Does Top Down Causation occur in physics?

- TDC1: Algorithmic:

To Be Contrasted with situations when this is not the case:

- Maxwell distribution for velocities in a gas
- Thermal conductivity of a metal
- Perfect gas laws
- Black body radiation
- All independent of the boundary conditions!

Where Does TDC occur in physics?
- TDC1: Algorithmic

(2) Whenever time changing environmental conditions control local physical outcomes

- Compression of a cylinder to heat up a gas

- Immersing an entity in a heat bath where the temperature steadily rises or falls
  (perhaps causing phase transitions)

- Nucleosynthesis in the early universe

Where Does TDC occur in physics?
- TDC1: Algorithmic

(3) When spatial boundary conditions at infinity determine outcomes

- Usual Newtonian gravitational theory (potential goes to zero at infinity)

- Usual electrostatics (potential goes to zero at infinity)
  Contrast: case of compact spatial sections, when overall charge has to be zero (Einstein, Wheeler)

- Usual electromagnetism (e.g. no incoming radiation condition)

- The origin of inertia?
  might be determined by matter at infinity (Mach's principle)

Where Does TDC occur in physics?
- TDC1: Algorithmic

(4) When boundary conditions at the start and/or end of time determine outcomes

- The arrow of time has to come from boundary conditions because local physical laws are time symmetric (Wheeler and Feynman, Penrose, Carroll)

- Olber's paradox: why is the night sky dark? Because we live in an evolving universe!

- Maybe the values of physical constants (the landscape of string theory: the vacuum in which we live is determined by cosmological initial conditions)

Where Does TDC occur in physics?
- TDC1: Algorithmic

(5) Whenever a potential is shaped so as to create complex structures that include channels controlling energy and information flows

- Piping in an industrial plant
- Wiring in an electric apparatus or electronic apparatus, e.g. a computer or oscilloscopes
- The axons and dendrites of a neuron in a brain, leading to the Hodgkin-Huxley equation

- More generally: any complex interaction network

Statistical laws then do not determine the specific outcome.

Where Does TDC occur in physics?

- TDC2: Information control

- feedback control loops/ feedback processes

Not in physics per se (not in physics textsbooks!)
but in many physics based contexts

- Mechanical engineering
- Electrical and Electronic engineering
- Chemical engineering

- ***?? Feedback processes in Astrophysics??***
- ***Effects related to galaxy formation in early universe***

Where Does TDC occur in physics?
TDC3: Adaptive selection

Selection from a (statistical) variety of initial states according to some higher level selection criterion

Enables apparent local violation of 2nd law of thermodynamics

(1): Maxwell's Demon: selection of higher energy molecules to go through a hole in a partition

Experimentally realised! http://arxiv.org/abs/1001.0944

(2): State preparation in QM (Isham)

(3): Decoherence in quantum theory, seen as environmental selection of pointer states (Zurek)

Where Does TDC occur in physics?
TDC5: Intelligent TDC

Whenever an experimenter does an experiment!

- Determining experimental outcomes
  (e.g. choice of spin axes)

- State preparation

- Starting the experiment!

- Designing the experiment!!

6: The nature of causality

The key point about *causality* in this context is that simultaneous multiple causality (inter-level, as well as within each level) is always in operation in complex systems.

Any attempt to characterise any partial cause as the whole (as characterised by the phrase `nothing but') is a fundamentally misleading position.

Indeed this is the essence of *fundamentalism*: claiming a partial truth to be the whole truth.

One must acknowledge the entire causal web in operation

There are always multiple levels of explanation that all hold at the same time: no single explanation

- so one can have a top-down system explanation as well as a bottom-up explanation, *both being simultaneously applicable*

e.g. Why aircraft fly [*Russell Ackoff*]

- the bottom up view: kinetic theory/Bernoulli's law
- the top down view: it was designed that way
- the same level view: the pilot is flying it to fulfill the timetable
- topmost: it makes a profit for the company

They are all simultaneously true and relevant!

It won't fly unless they all apply at the same time.

Causality: Aristotle's kinds

The material cause: "that out of which",
The formal cause: "the form", "the account of what-it-is-to-be".
The efficient cause: "the primary source of the change or rest"
The final cause: "the end, that for the sake of which a thing is done"

We can adapt Aristotle's categorisation to the hierarchical context considered here, by seeing
the Material Cause as the lower level (Physical) cause,
the Formal Cause as the same level (Immediate) cause,
the Efficient Cause as the immediate higher (Contextual) cause,
the Final Cause as the ultimate higher level cause

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

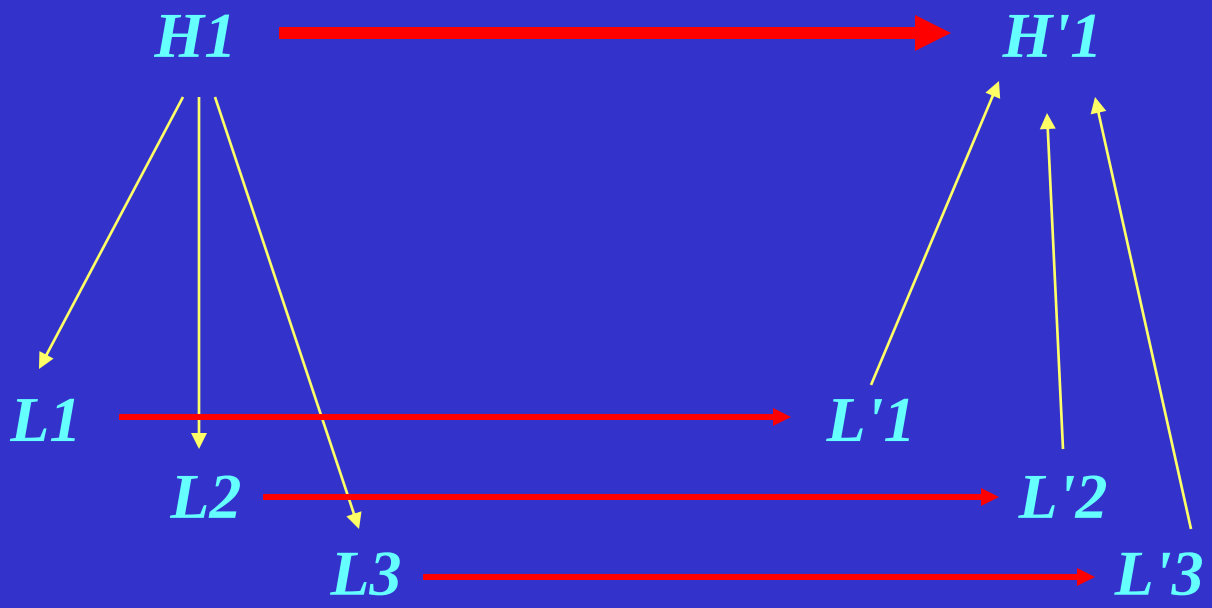
- When you coarse grain, all of these lower level states correspond to the same higher level state
-Entropy is a measure of how many lower level states correspond to a specific higher level state (Penrose)

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

- However note that not all higher level variables can be obtained by coarse graining

Reliable emergent higher level behaviour

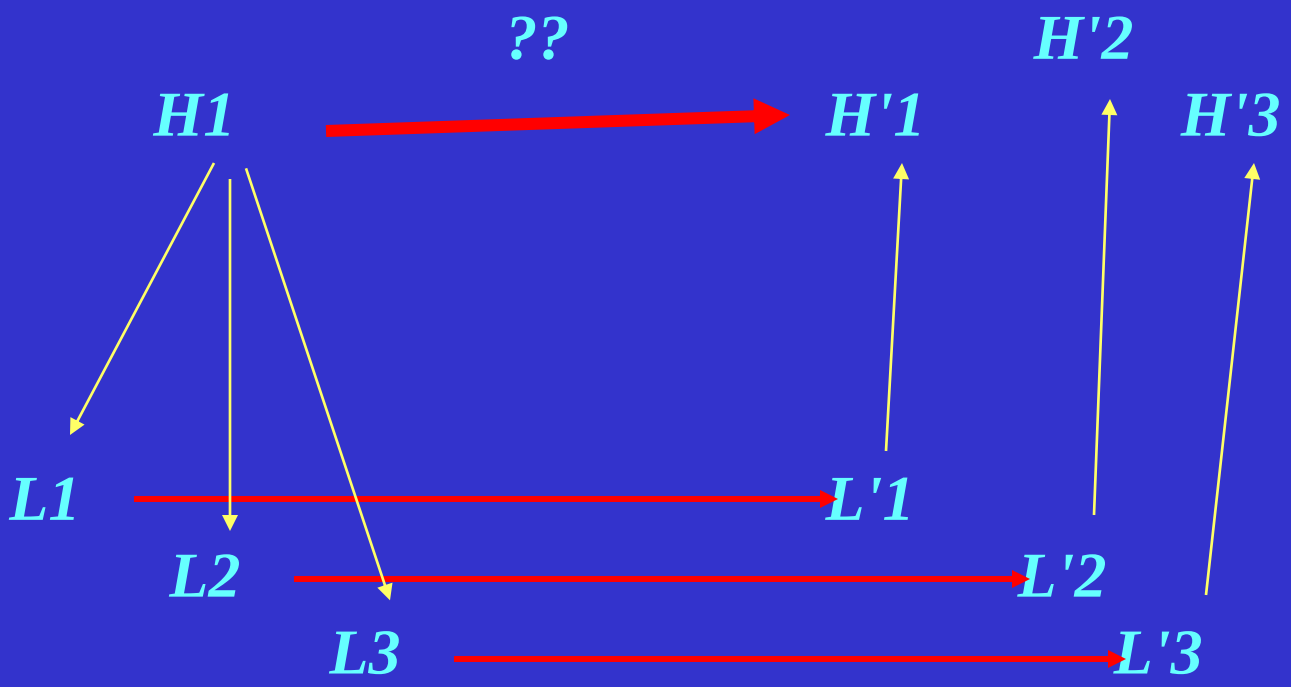
Set initial higher level state: what transpires?



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.

Example: gas laws, electronic apparatus such as computers

No reliable higher level behaviour:



The lower level dynamics does not lead to coherent higher level dynamics when the lower level dynamics acting on different lower level states corresponding to a single higher level state, give new lower level states corresponding to different higher level states.

Example: chaotic systems: weather

7 Completeness of physics?

Human thought and physics :

- *Human thoughts can cause real physical effects*
- *This is a top-down action from the mind to the physical world*
- *This is not included in what physics deals with*

For example: Chess

Physics cannot predict the movement of chess pieces as that involves human volition – it cannot predict the choices that will be made

Physics cannot even characterize the origin of the possibility space for chess pieces – the set of allowed moves – as that derives from social agreements
There is no charge and force field for each kind of chess piece.

`Fundamental physics'

`Fundamental physics'

Human thought and physics :

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For example: Chess

Physics cannot predict the movement of chess pieces as that involves human volition – it cannot predict the choices that will be made

Physics cannot even characterize the origin of the possibility space for chess pieces – the set of allowed moves – as that derives from social agreements that are not confined to any single brain.
There is no charge and force field for each kind of chess piece.

Q: Could these high level theories and outcomes not be implied uniquely by the data in the early universe? – they set the initial conditions and all proceeds algorithmically thereafter

A: No. The existence of Maxwell's electromagnetic theory and quantum field theory cannot be plausibly explained by physics alone, because of the cosmic context.

Unpredictable quantum fluctuations during inflation in the vary early universe provided the seeds for large scale structure formation.

The specific outcomes – such as the existence of our Galaxy – were not causally determined by the initial data

Quantum uncertainty means that *physical outcome is not uniquely determined even in principle*. This is not always negligible at the macro level, despite occurring at a micro-level.

If the origin of galaxies and clusters of galaxies was not causally determined by the initial data then neither was our own individual existence necessarily implied by that data

- nor any thoughts we may have

Furthermore evolutionary history on Earth was also crucially affected by quantum uncertainty,
because cosmic rays cause mutations in DNA
- And their emission was via quantum events

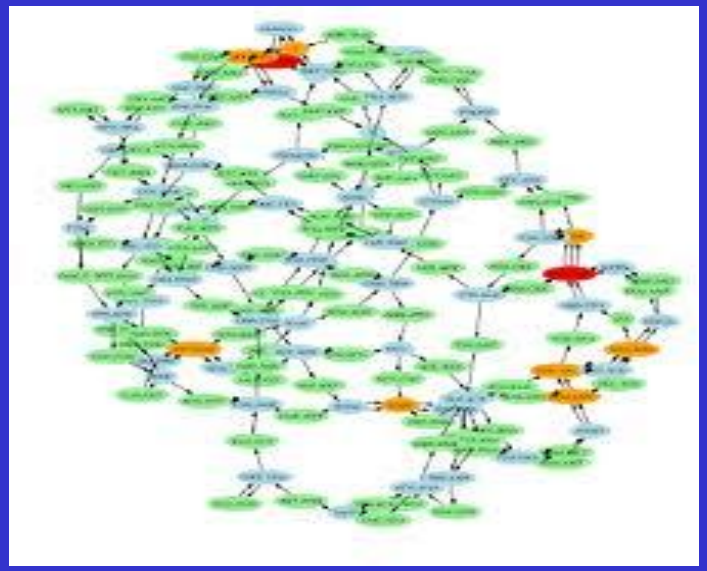
- Current existence of giraffes and humans is not uniquely implied by the initial data on Earth after it had formed

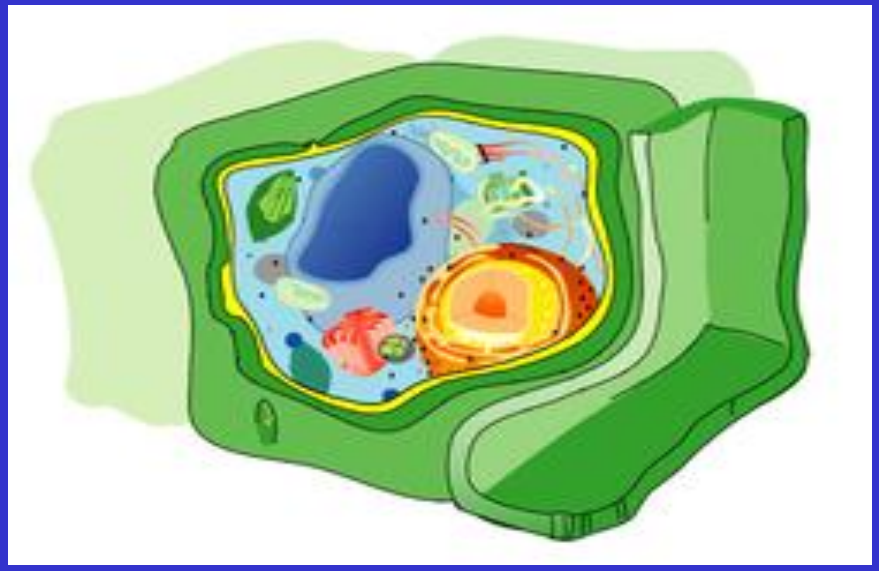
- The cosmic context: Physics cannot give a complete causal account of what happens because if it did they would be uniquely determined by the random initial data for the universe at the time of decoupling of matter and radiation

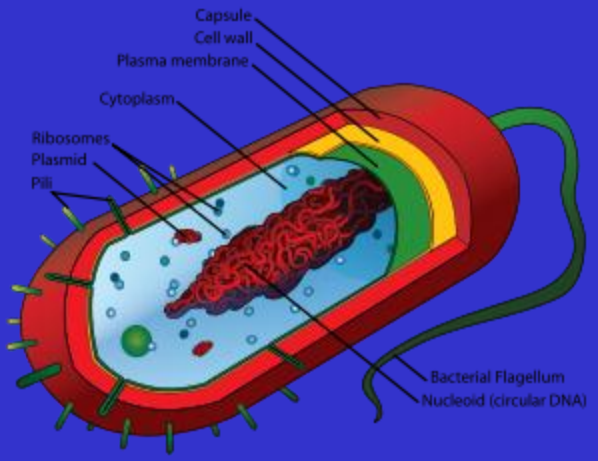
- The content of this talk would be implied by that data. That is not remotely plausible, and indeed quantum uncertainty makes it impossible.

- Meaning comes into being that did not exist at earlier times. This is possible only because the higher levels develop their own autonomous powers independent of the lower levels of causality and structure,
- as allowed by the possibility space created by the underlying physics.

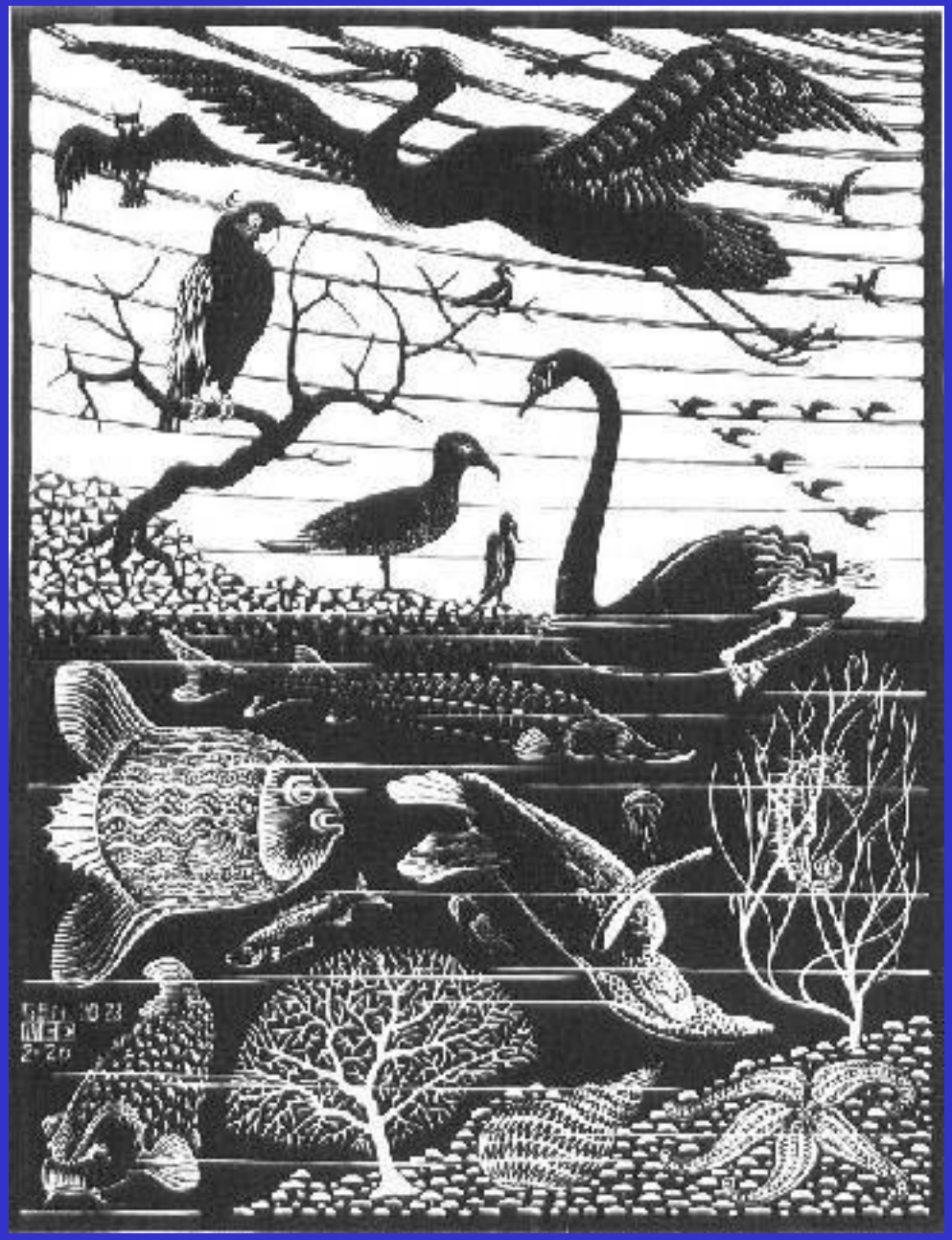
- ***The Challenge: Showing how physics and chemistry can underlie higher levels of existence with their own autonomous causal powers***.






Capsule
Cell wall
Plasma membrane
Cytoplasm
Ribosomes
Plasmid
Pili
Bacterial Flagellum
Nucleoid (circular DNA)

Fifth day of creation:
M C Escher



Q: When is top down causation very well proven?

A: Between the mind and society

- Cultural Neuroscience (Chiao and Ambady)

B: In the mind and brain

- E.g. vision (Dale Purves: *Brains: how they seem to work*)
- Environmental Enrichment effects on brain (Kempermann)

C: In physiology:

- e.g. the heart (Denis Noble: *The Music of life)*

D: Evolutionary Theory

- Documented effects of change of environment on genes

- *Nature* **386**, 493 - 495 (03 April 1997);

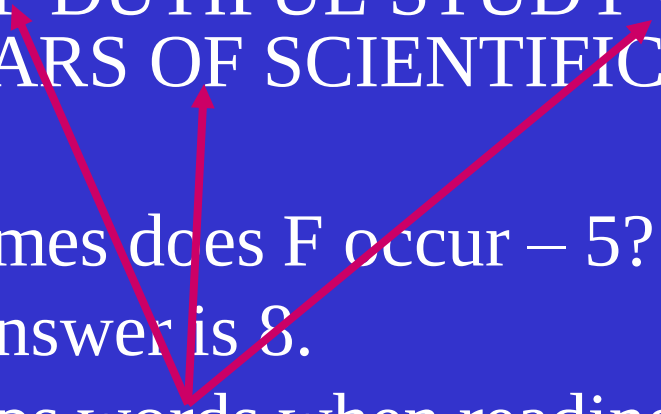
- **More hippocampal neurons in adult mice living in an enriched environment**
- GERD KEMPERMANN, H. GEORG KUHN & FRED H. GAGE
- The Salk Institute for Biological Studies, La Jolla, California 92037, USA

- Neurogenesis occurs in the dentate gyrus of the hippocampus throughout the life of a rodent1–4, but the function of these new neurons and the mechanisms that regulate their birth are unknown. Here we show that significantly more new neurons exist in the dentate gyrus of mice exposed to an enriched environment compared with littermates housed in standard cages. We also show, using unbiased stereology, that the enriched mice have a larger hippocampal granule cell layer and 15 per cent more granule cell neurons in the dentate gyrus.

Proof of top-down effects in reading text: context drives the process of reading (it is not bottom up)

Read the following statement once and as you are doing so count the number of times the letter “F” appears:

FINAL FOLIOS SEEM TO RESULT FROM YEARS OF DUTIFUL STUDY OF TEXTS ALONG WITH YEARS OF SCIENTIFIC EXPERIENCE



How many times does F occur – 5? 6? 7?

The correct answer is 8.

The mind skips words when reading!

You don’t even see them

Francis Crick famously said

"*You, your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of nerve cells and their associated molecules*".

But nerve cells and molecules are made of electrons plus protons and neutrons, which are themselves made of quarks .. so why not

"*You, your joys and your sorrows, your memories and your ambitions, your sense of personal identity and free will, are in fact no more than the behavior of a vast assembly of quarks and electrons*"?

And these themselves are possibly vibrations of superstrings.

The Effectiveness of Consciousness

Dimensions of consciousness:

- rationality and understanding
- feelings and intentions
- social systems/constructions, e.g. laws/money

• *Concepts are not the same as brain states*

- *They can be represented in many different ways*

• *These are all causally efficient: they effect the nature of physical objects in the world*

• *These function are based in neuronal structure*

A timetable for an airline determines when aircraft fly in a more or less reliable way. It results in an aircraft flying on a particular path at a particular time, resulting in particular patterns of atmospheric pollution through specific molecules.

How do you demonstrate top-down causation? - change the timetable and different patterns of pollution will result.

Physics can describe the material out of which the timetable is made and the ink markings on the paper; it cannot comprehend the causal chain by which this leads to particular aircraft flying at particular times. The relevant variables (the entries in the timetable) belong to an irreducible equivalence class of abstract entities coding information that controls what happens in the real world.

Hierarchical structure: 2

Cosmology	Sociology
Astronomy	Psychology
Geology	Physiology
Materials	Biochemistry

Chemistry
Physics
Particle Physics

Hierarchy of causal relations

* ***The right hand side involves goals & conscious choices***

Implication

Thus even if physics attains its goal of a "Theory of Everything" such as M-theory, it will be causally incomplete because it will not include in its ambit human intention .
This is not a statement of vitalism or dualism: it is a simple fact about the nature of physics, independent of your theory of the brain

Yes of course elementary forces determine what happens in then brain in a bottom up way – but that is only part of the picture
- *top down action is also taking place implementing higher level meaning, which is why physics alone cannot give an answer*

- Just stating `what happens at higher levels is determined by these bottom-up interactions' is a theory with zero predictive power.
It does not begin to characterise what is actually going on or the nature of the outcomes, which have crucial higher level aspects.

The origin of biological information

It is the systematic use of meaningful information – e.g. that stored in DNA - that distinguishes biology from physics.

How does that information arise?

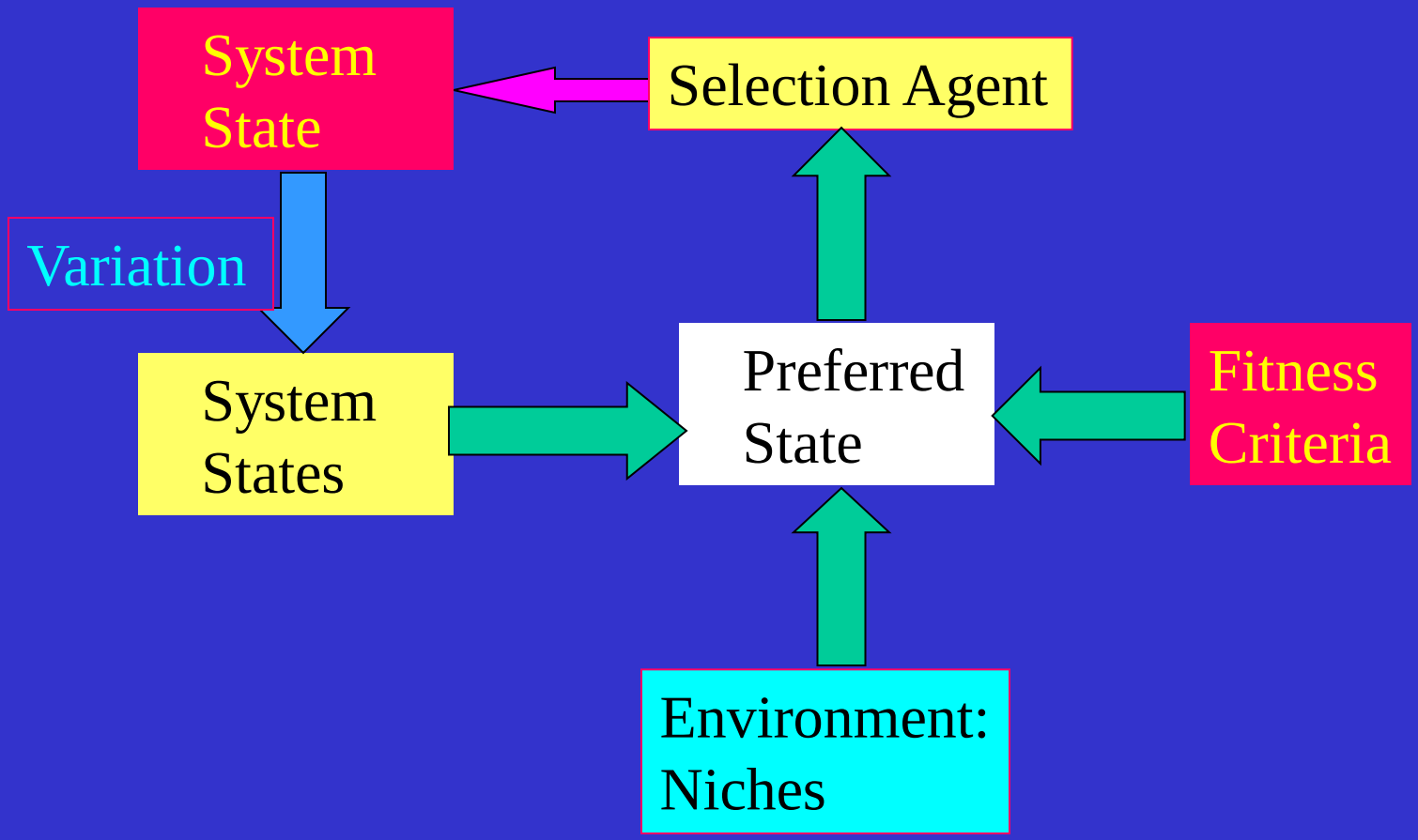
By adaptive selection of meaningful information from a much larger pool of random information, according to higher level selection criteria (hence top-down action)

-throwing away all the rest leaves behind a meaningful set of data, this is a mechanism enabling flowing against the stream of increasing entropy - allowed, but not explained, by interchange of entropy with the environment (Prigogine)

“Darwin’s Demon”, in analogy with Maxwell’s demon

Adaptive Selection:

generation of adapted states with new information encoded



Neural Networks Training of artificial neural nets to perform a specific task (say letter recognition) determines the interaction weights in the network. The niche is a particular set of letters to be recognised. The fitness criterion is correct pattern recognition, and the adaptive process is the training of the neural network. This is a form of top-down causation from the pattern to be recognized (a high-level concept, as it is defined in terms of the relation between the elements) to the low-level property of network weights. Decision making is a property of the network rather than of any single cell.

Genetic algorithms (implemented on digital computers) are specifically designed to solve problems in an adaptive way. A `fitness function' is defined over the genetic representation and measures the quality of the represented solution, thus providing the needed fitness criteria in this case.

Three contexts of emergence:

1st: Evolutionary history of the universe and the world:

Once upon a time they did not exist!

2nd: Developmental history of each living being:

Once upon a time they were a single cell.

3rd: Functional nature of each complex object:

built up out of components that do not have the higher level properties.

Summing up

Q: When does physics per se give a good answer?

A: There are restricted special circumstances – isolated systems of rigid structure or interacting only in highly restricted ways and with a non-interference condition holding – where a high level of repeatability is possible, and physics gives good predictions.

However even then, most actual physics predictions are statistical rather than deterministic

Linking the levels

Statistical physics (Boltzmann), solid state physics, theory of Chemical bond – at lower levels

Network theory – at higher levels

- *Analysis of biological networks*, Junker and Schreiber
- *Networks in the brain*, Sporn

Based in graph theory

But statistics does not capture the essence of what is going on

Hierarchical structure, module detection, network motifs (*An Introduction to Systems Biology* Uri Alon)

Complexity in computer science:

Grady Booch, *Object Oriented Analysis and Design*

(class structure, information hiding, inheritance)

The final outcome is not determined uniquely by the initial data

*New information comes in via **quantum uncertainty**, amplified by various mechanisms e.g. **chaotic systems***

- *The effect of initial data is damped out by existence of **attractors** in possibility space, particularly **friction** effects*

*The higher levels can have causal autonomy through various processes: **Top down action** sets the context of local physics through boundary conditions and structural conditions,*

*- The effect of initial data is damped out by existence of **goals** in feedback control systems*

- *The context can change the nature of micro-interactions by affecting constituent properties: **altered equations of state***

6: Summing up

Q: How can top down action take place without violating the causal closure of physics: if everything is physically determined from a micro level, how can genuine top down action be possible?

A: Physics is not causally closed! Quantum theory has still not percolated into the minds of biologists, neuroscientists, and philosophers – even many physicists. According to physics, the future is not predictable, even in principle, in general. Physics creates a possibility space of a variety of physical states and lays down constraints on how changes between them may take place. Top down action chooses which actually occurs