The interactions of Physics, Environmental, and Developmental Issues: Taking complexity Seriously

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1: Our aim: making a real difference in Africa

2: Some issues are essentially physics based

3: Some relate to complexity: hierarchies everywhere

4: Causation: always contextual

5: The crises facing us

6: Taking action: values, evidence, and emotions

1. Our aim: making a real difference in Africa

The Big Picture:

a) Physics is worth doing in its own right

➔ Helping students to reach an international level in all physics areas

b) Using physical expertise to help improve life on the continent

➔ in which ways is this possible?

For an overview of these issues, see via Google Scholar,
"Science research policy in South Africa", G. Ellis (1994)
- a report to the *Royal Society of South Africa* at the time of the democratic transition in this country

Making a real difference in Africa

In looking at these issues, we have to deal with the interactions of Physics, Environmental issues, and Economic/Developmental issues

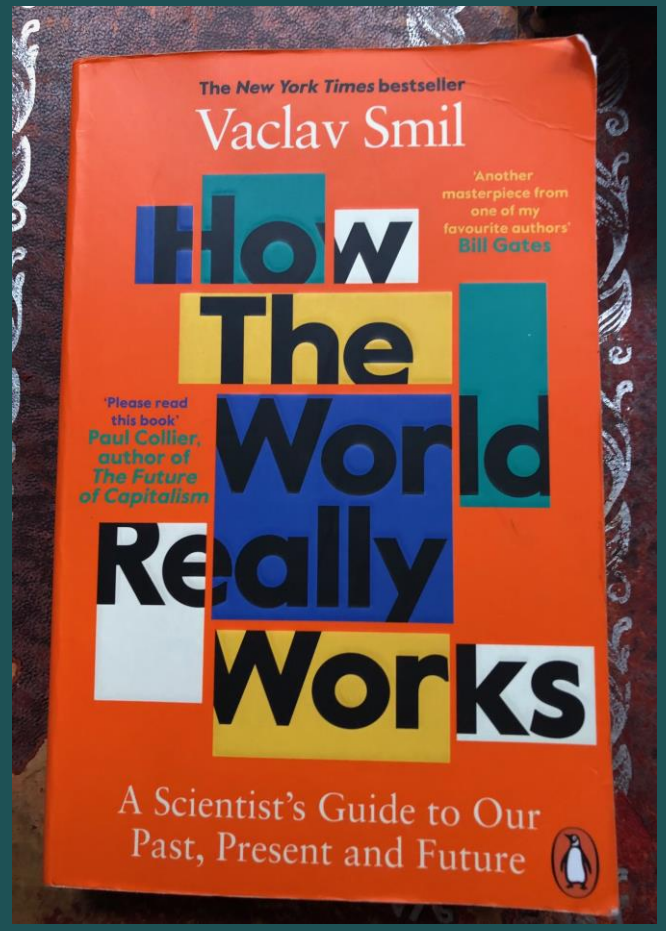
These are very complex interactions

We must take their complexity seriously, and so investigate a bit the basis of how complex systems work**.** This involves their hierarchical nature.

2: Some developmental issues are essentially physics based

Physics underlies all that emerges, including ecosystems and societies, and some issues to do with energy usage and global warming have direct relations to physics, as pointed out by Vaclav Smil.

He gives numbers for everything!



Smil: Understanding energy

- Energy conversions are the basis of life and evolution and economic systems.
- Large nuclear reactors are the most reliable producers of electricity.
- The advantages of liquid fuels are high energy density, and ease of production, storage, and distribution.
- Lubricants are needed to minimize friction in everything.
- Electricity's use is effortless and clean, but its problem is storability.
- Global warming concerns have led to widespread calls for doing away with fossil fuels as soon as possible – inter alia modern nuclear reactors are needed.

Smil: Understanding food production

- Highly mechanised farming requires non-renewable anthropogenic energies (i.e. they influence nature) derived overwhelmingly from coal.
- Farm machines of many kinds consume fossil fuel - diesel or gasoline – directly.
- The energies used for these purposes are dwarfed by the energy requirements of producing agrochemicals. Fertilizers use large quantities of potassium, phosphate, and ammonia.
- Bread, chicken, and tomatoes have different energy requirements, with chicken most efficient and tomatoes with a high energy cost.
- Capturing seafood is the most energy intensive process of food provision, because of the diesel oil used.

Smil: understanding our material world
- the four pillars of modern civilisation

1. Ammonia (NH_3): the gas that feeds half the world
   (it provides fertilizer for agriculture via the Haber-Bosch process).

2. Plastics: diverse, useful, but causing troublesome pollution
   Celluloids, polyethelyne, polypropylene, polyvinyl chloride (PVC), etc
   Can be formed by casting, pressing, or extruding
   Crucial to health care (PVCs) and Personal Protective Equipment (PPE)

3. Steel: ubiquitous and recyclable
   Mass transport, in the home, appliances, automobiles, reinforced concrete, bridges, machine tools, weapons, etc.

4. Concrete: a world created by cement
   Buildings, transportation infrastructure, airport runways, dams, etc.

Smil: Understanding the environment

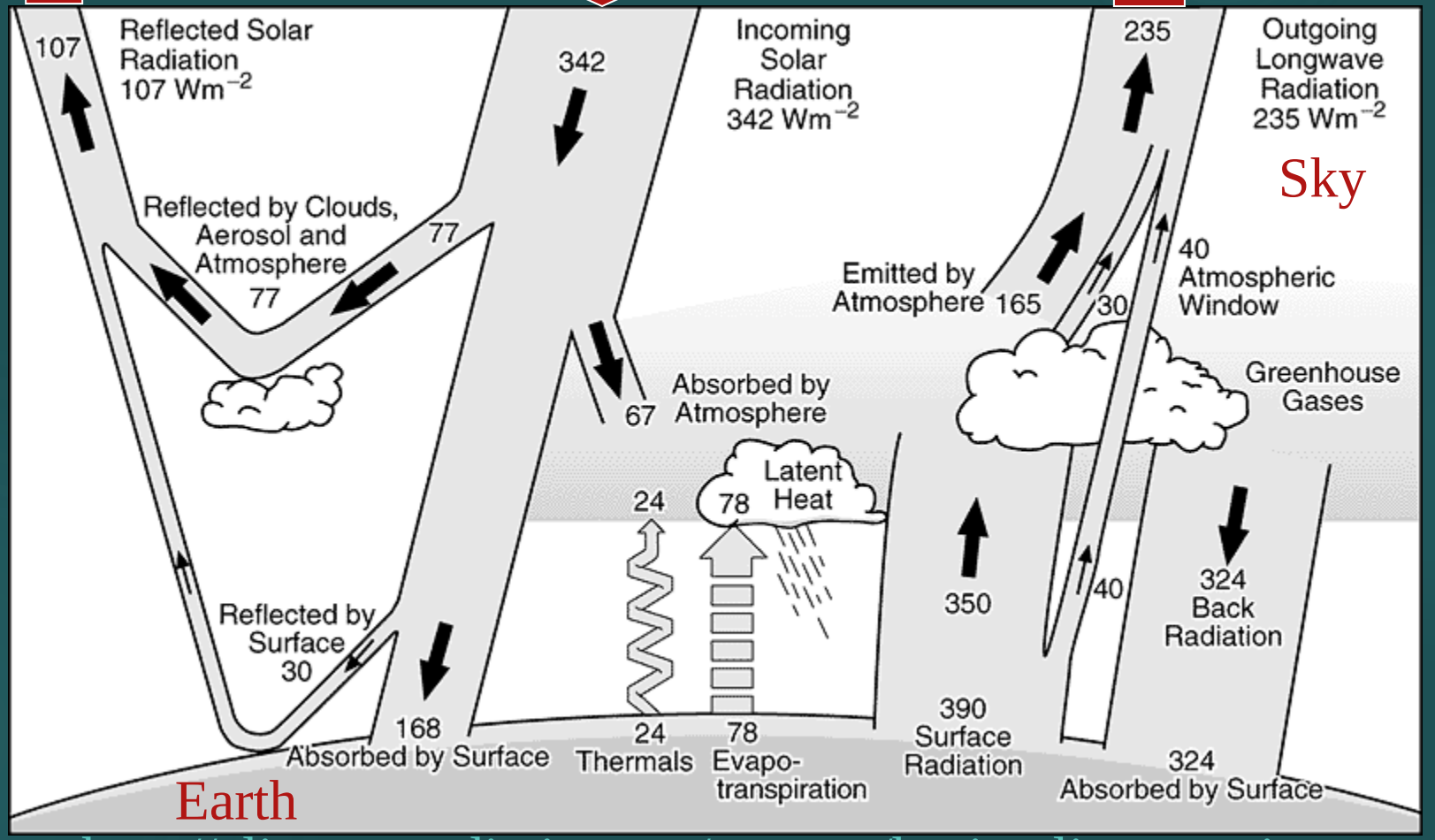
- Oxygen – the most vital element for life - is not in danger.
- Water is a crucial but almost universally mismanaged resource.
- Food Production is taking up about a third of non-glaciated land, and uses much fertilizer and energy. The main problem with plant nutrients is their unwanted presence in water.
- The greenhouse effect keeps the Earth from being permanently frozen.
- Global warming is due to anthropogenic (human driven) emission of CO_2, methane (CH_4), and nitrous oxide (N_2O). This puts at risk global water supply but not necessarily global food supply. It is accompanied by massive floods and fires.

It is a truly global phenomenon: its largest anthropogenic cause is the combustion of fuels that constitute the energetic foundations of modern civilisation.

Out

In

Out



http://climateprediction.net/content/basic-climate-science

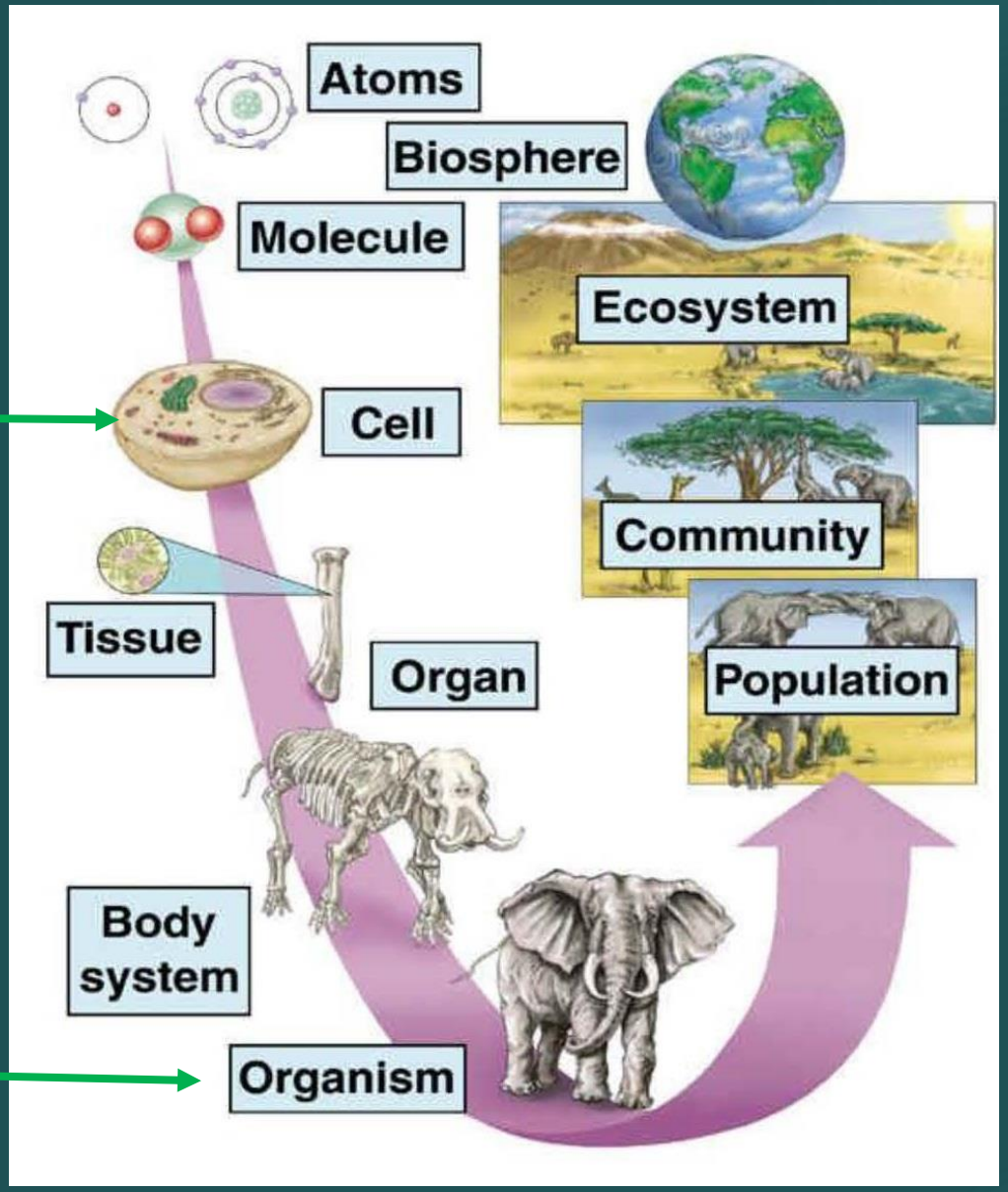
The greenhouse effect, powered by nuclear fusion in the Sun, is necessary for life.
It is possible because the dark night sky acts as a heat sink: a link to cosmology.

3: Some issues relate to Complexity: Hierarchies everywhere

The basic principles:

- Break up a complex task into simpler tasks.
- Create modules to handle the simpler tasks.
- Repeat, until a level is reached where the task can be solved.
- Combine the outcomes to produce a solution to the complex task.
- Hide the internal workings of the modules from the external world.

The modular structure of life



The first level that has all the functions of life

Enables populations to exist

Enables individuals to exist

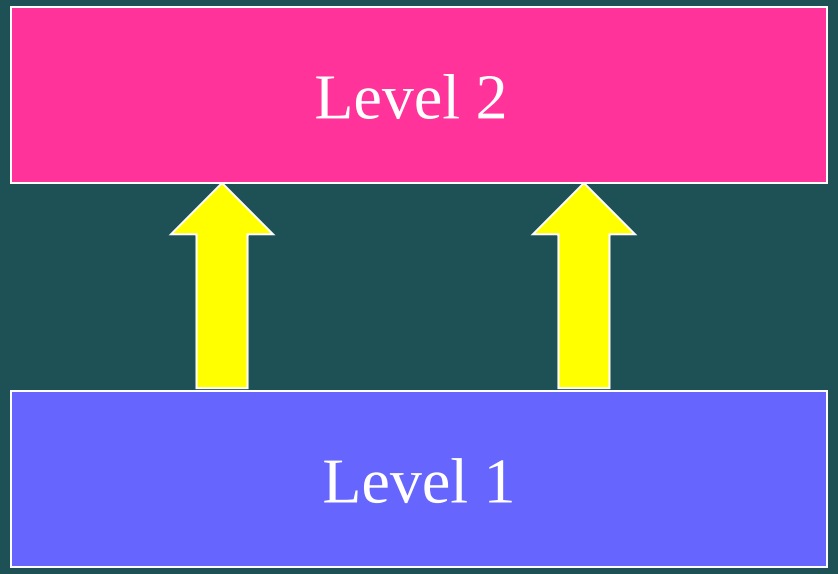
The level where agency occurs

Hierarchies of Causation and Structure

Level 10:	Cosmology	Sociology/Economics/Politics
Level 9:	Astronomy	Psychology
Level 8:	Space science	Physiology
Level 7:	Geology, Earth science	Cell biology
Level 6:	Materials science	Biochemistry
Level 5:	Physical Chemistry	Chemistry
Level 4:	Atomic Physics	Atomic Physics
Level 2:	Particle physics	Particle physics
Level 1:	Fundamental Theory	Fundamental Theory

Different emergent effective laws, in terms of appropriate variables, at each level.

All levels are needed for the whole to function (Denis Noble).



Bottom-up causation alone:

Micro forces determine what happens at the higher levels:
Higher level structure, new properties emerges from lower level components; new kinds of variables and laws come into being

- **occurs between each pair of levels**
- **hence chains from bottom upwards**

Life Hierarchy of Structure and Causation

Sociology/Economics/Politics

Psychology

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

Botany/Zoology/Physiology

Cell biology

Biochemistry

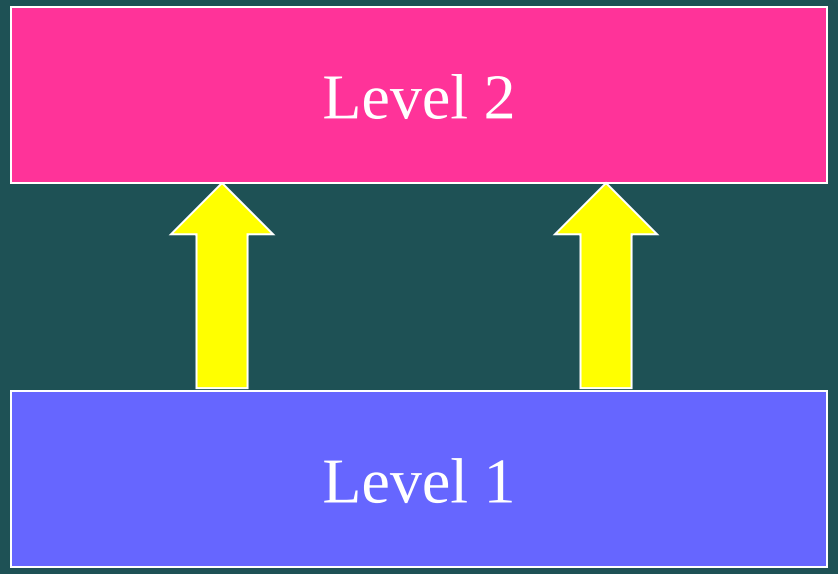
Chemistry

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

Atomic Physics

micro-physics underlies macro physics, e.g. kinetic theory of gases

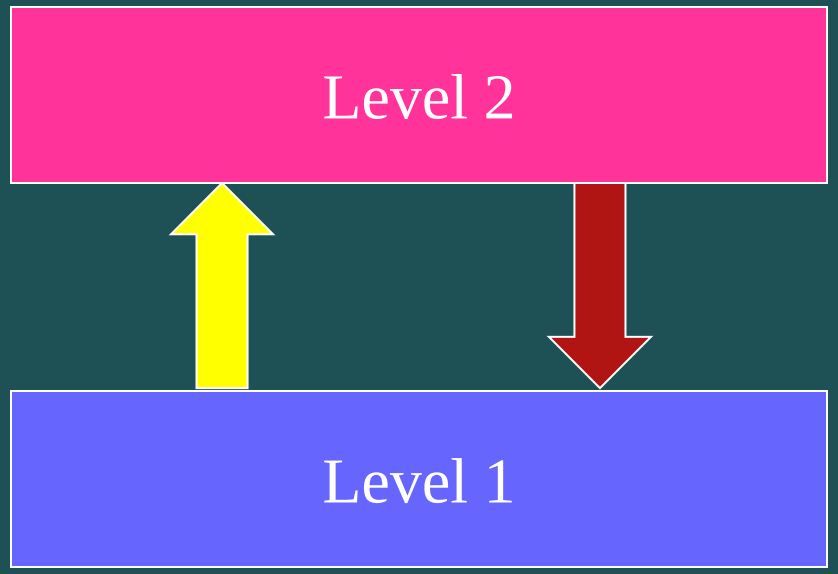
Particle physics



Bottom-up and top-down causation:

Contextual effects occur when the higher levels of the hierarchy causally effect what happens at the lower levels,
in a coordinated way.

Happens between adjacent layers: so chains down



Bottom-up and top-down causation:

Contextual effects occur when the higher levels of the hierarchy causally affect what happens at the lower levels,
in a coordinated way.

This happens between adjacent layers: and so chains down

The Hierarchy of Structure and Causation

Sociology/Economics/Politics

Psychology

- *the mind controls physiological events such as walking*

Botany/Zoology/Physiology

- *epigenetics determines what happens in cell biology*

Cell biology

- *cell processes initiate chemical cycles*

Biochemistry

Chemistry

Atomic Physics

Particle physics

Causation in computers: Hardware

Level 7: Global Network
Level 6: Local Network
Level 5: Computer
Level 4: Motherboard, Memory banks
Level 3: CPU, memory circuits
Level 2: ALU, primary memory, bus
Level 1: Logic circuits , Registers
Level 0: Transistors, resistors, capacitors
Level -1: Atoms
Level -2: Nucleons
Level -3: Quarks
Level -4: Superstrings

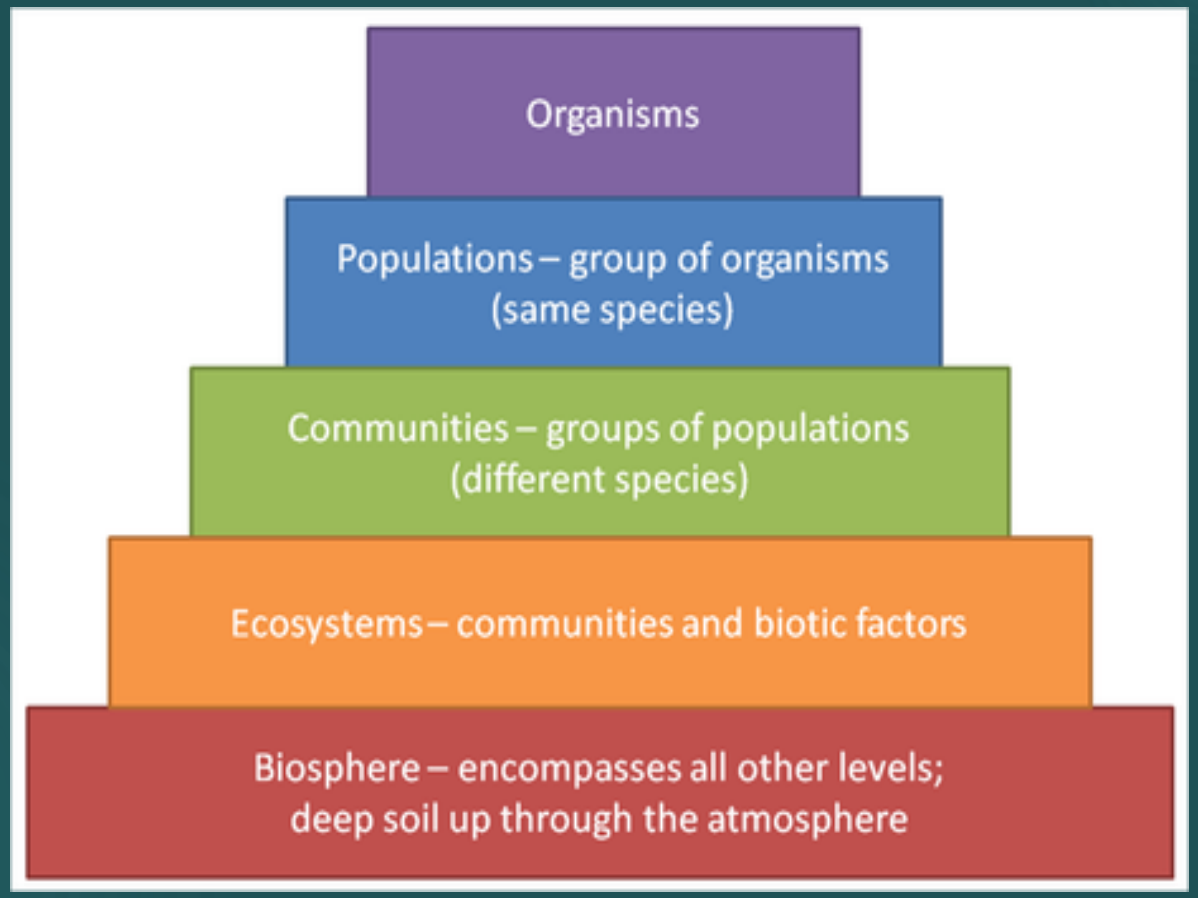
What determines what happens? Software!

Causation in computers: Software

Level 7: Applications programs	Data
Level 6: Problem oriented language level	Classes, Objects
Level 5: Assembly language level	Symbolic names
Level 4: Operating system machine level	Virtual memory, paging
Level 3: Instruction set architecture level	Machine language
Level 2: Microarchitecture level	Microprograms
Level 1: Digital logic level	Gates, registers
Level 0: Device level	Transistors, connectors

What determines what happens?

The higher levels drive the lower levels: their logic determines what happens



Levels of organisation in ecology

(depicted the other way up: small at the top)

4: Causation: always contextual

How does complexity such as life arise from physics? A key issue

Both upwards and downwards causation take place in emergent hierarchies. The latter occurs by

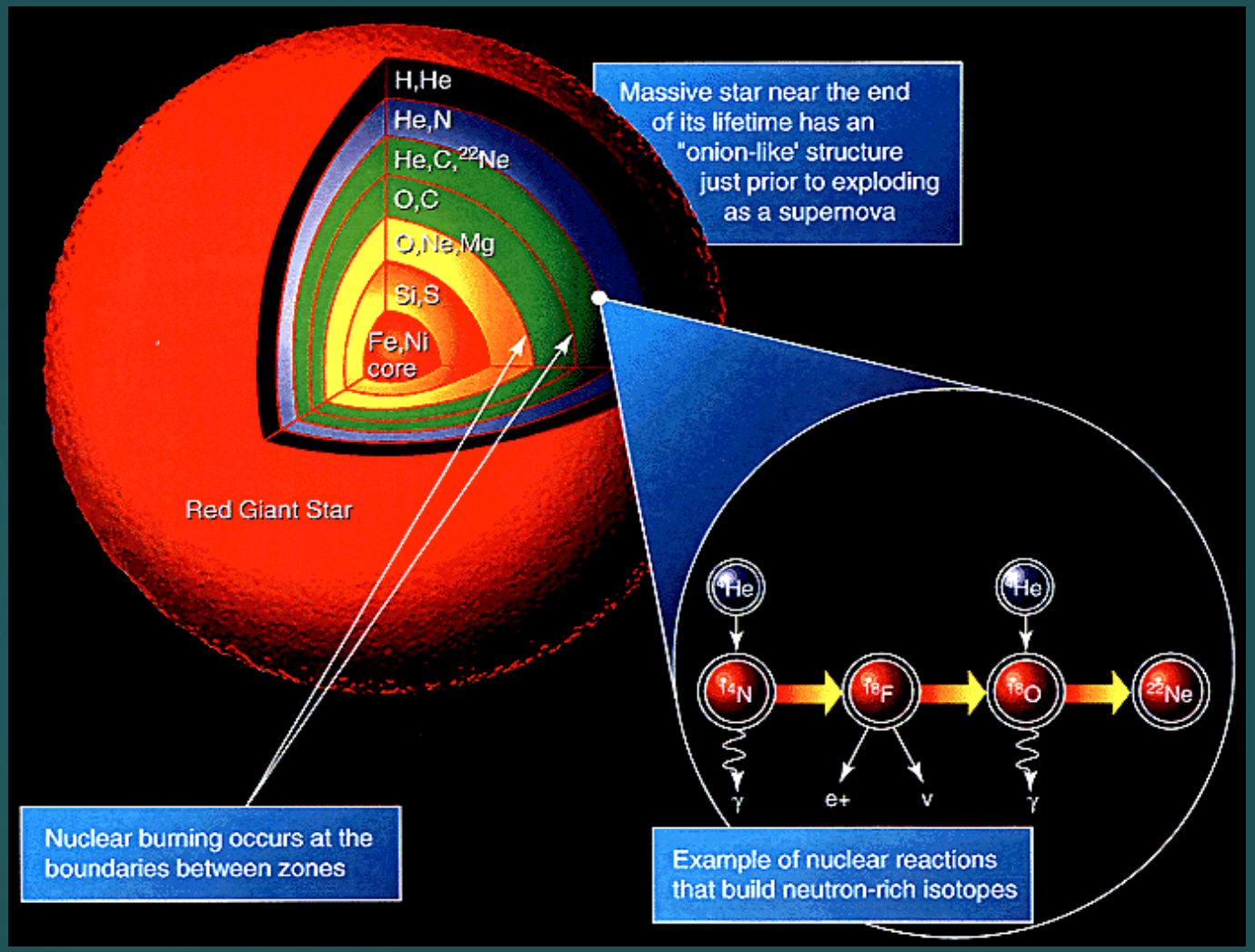
- Setting boundary conditions and constraints.

  e.g. electric wires channel the flow of electrons

- Creating, modifying, and deleting lower-level elements.

  e.g. chemical processes that create new molecules

Example 1: The synthesis of elements in stars



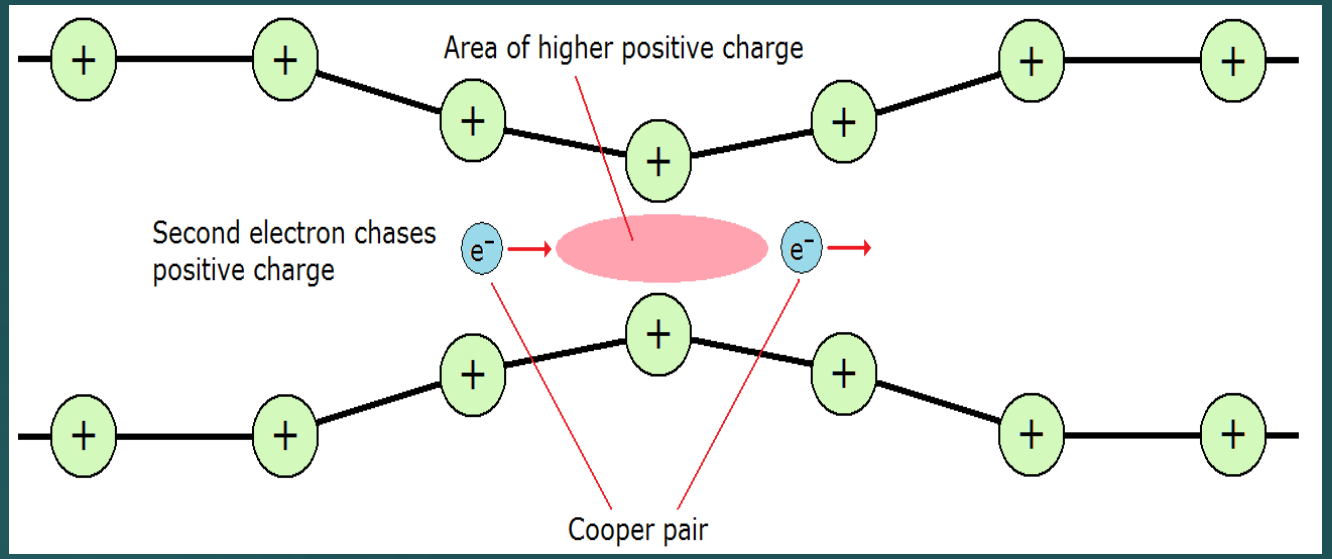
Contextual effect:

The outcomes of standard nuclear reactions are determined by the structure of the star, which determines temperature and pressure as a function of radius

Downwards creation:

This changes the elements making up the star, so Carbon and Iron come into being

Example 2: The superconductivity of specific materials



Electrons repel each other! Lattice distortions act downwards to create the **Cooper pairs** that enable superconductivity to take place.

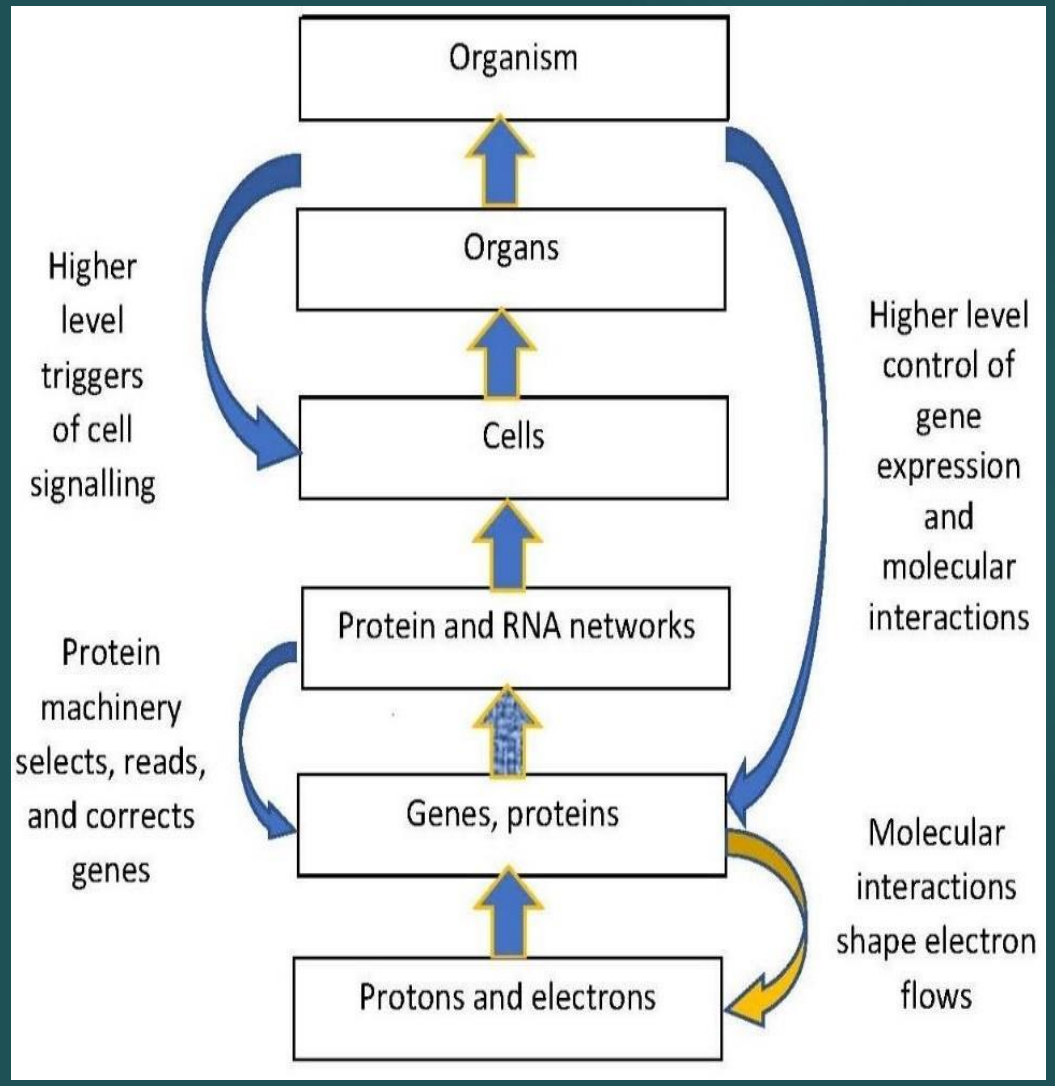
Similarly crystal structures lead to existence of **quasi particles** such as **phonons** that determine solid state material properties.

Example 3: Biological functioning of an individual

Both upwards and downwards causal effects occur (D. Noble)

Gene regulatory networks create new elements (proteins) that are needed for biological functioning

The physical basis of these effects is molecular signalling and change of shape of macro-molecules (J-M. Lehn)



Example 4: The origin of biological information

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** based on random mutations, 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*.

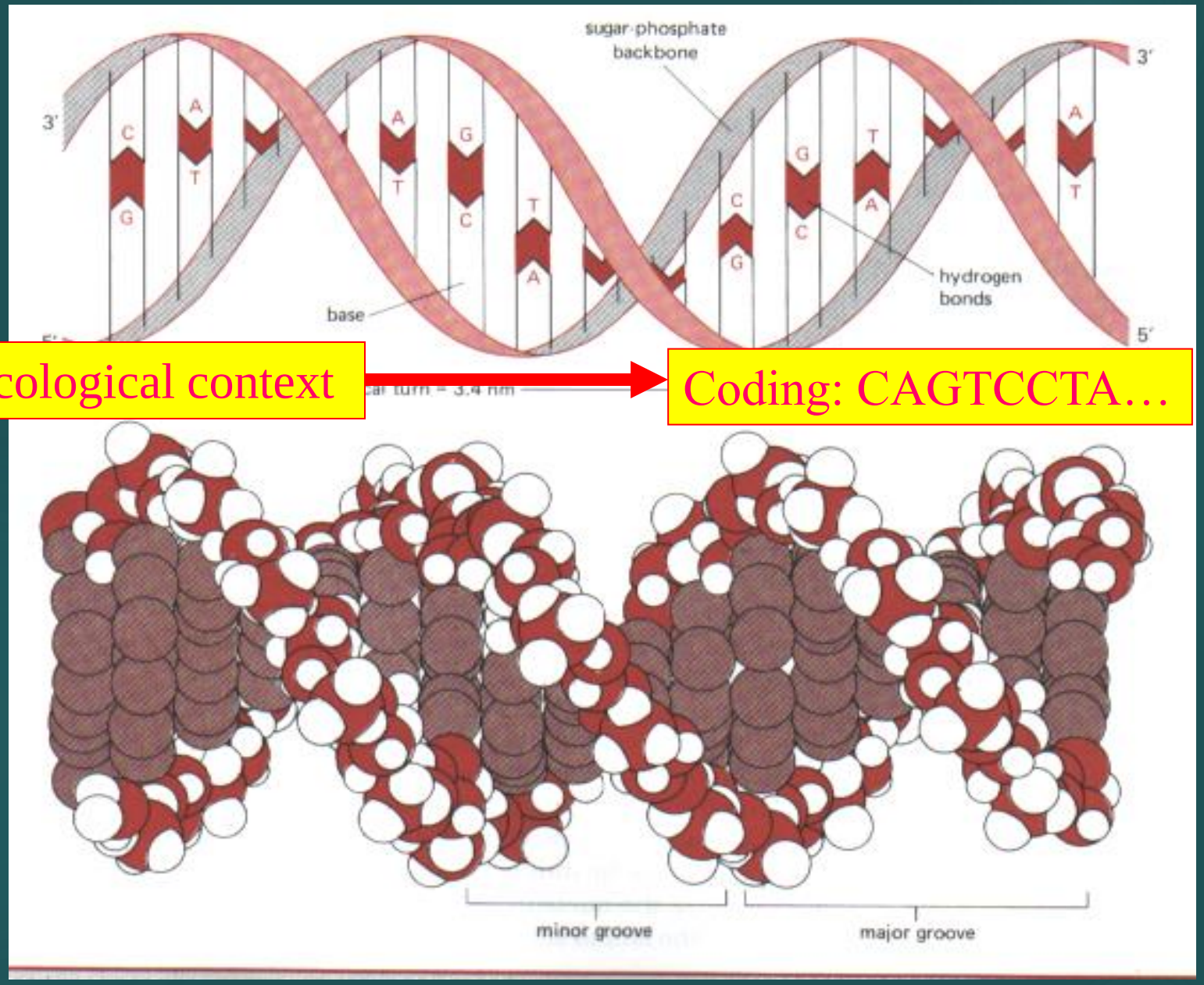
This is the way new information comes into biological processes. It is unpredictable because a random element enters.

Environment

Animal

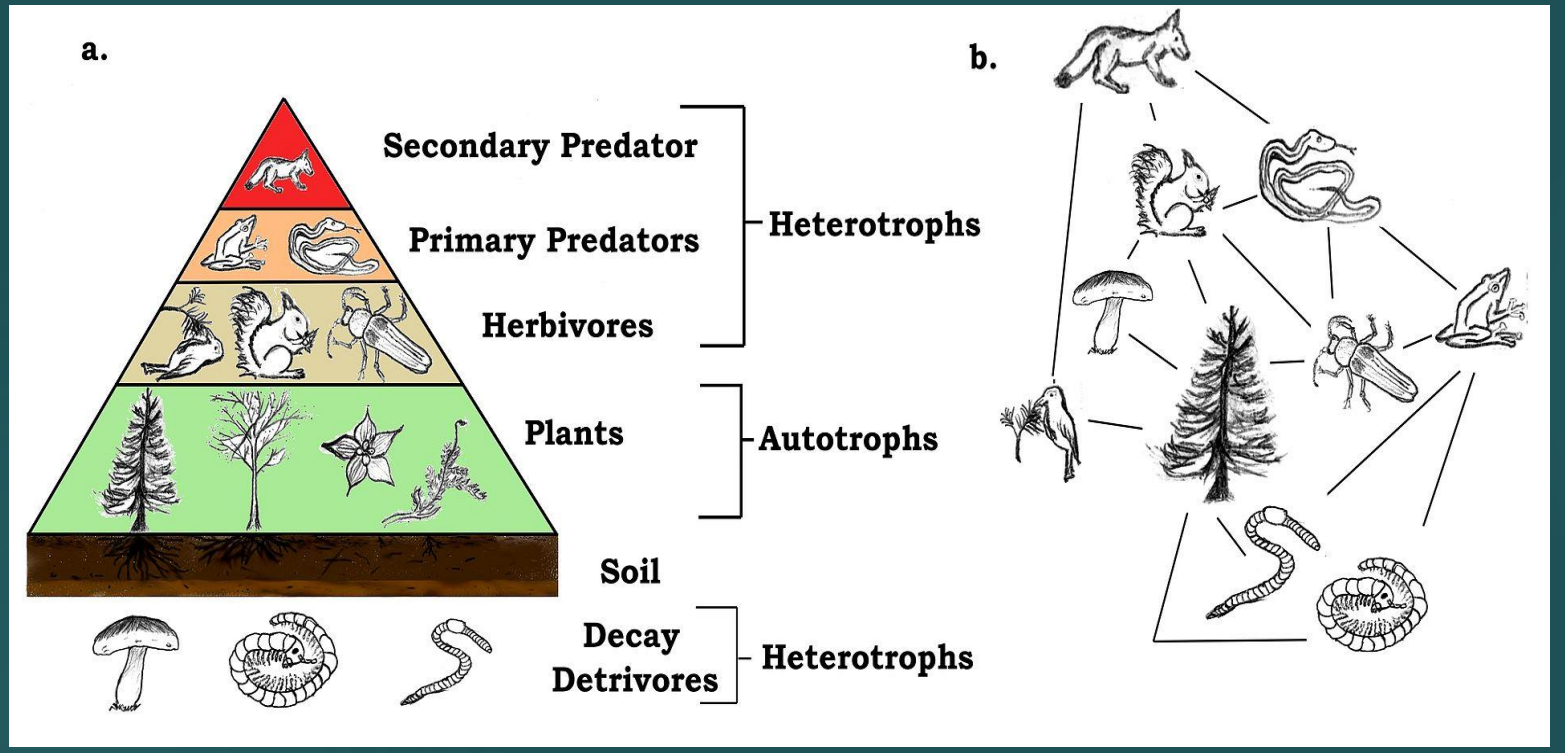
DNA sequence

Through natural selection, top-down action from the environment codes information about appropriate responses to the environment into the detailed base sequence in the animal's DNA.



The DNA double helix, with complementary base pairs.

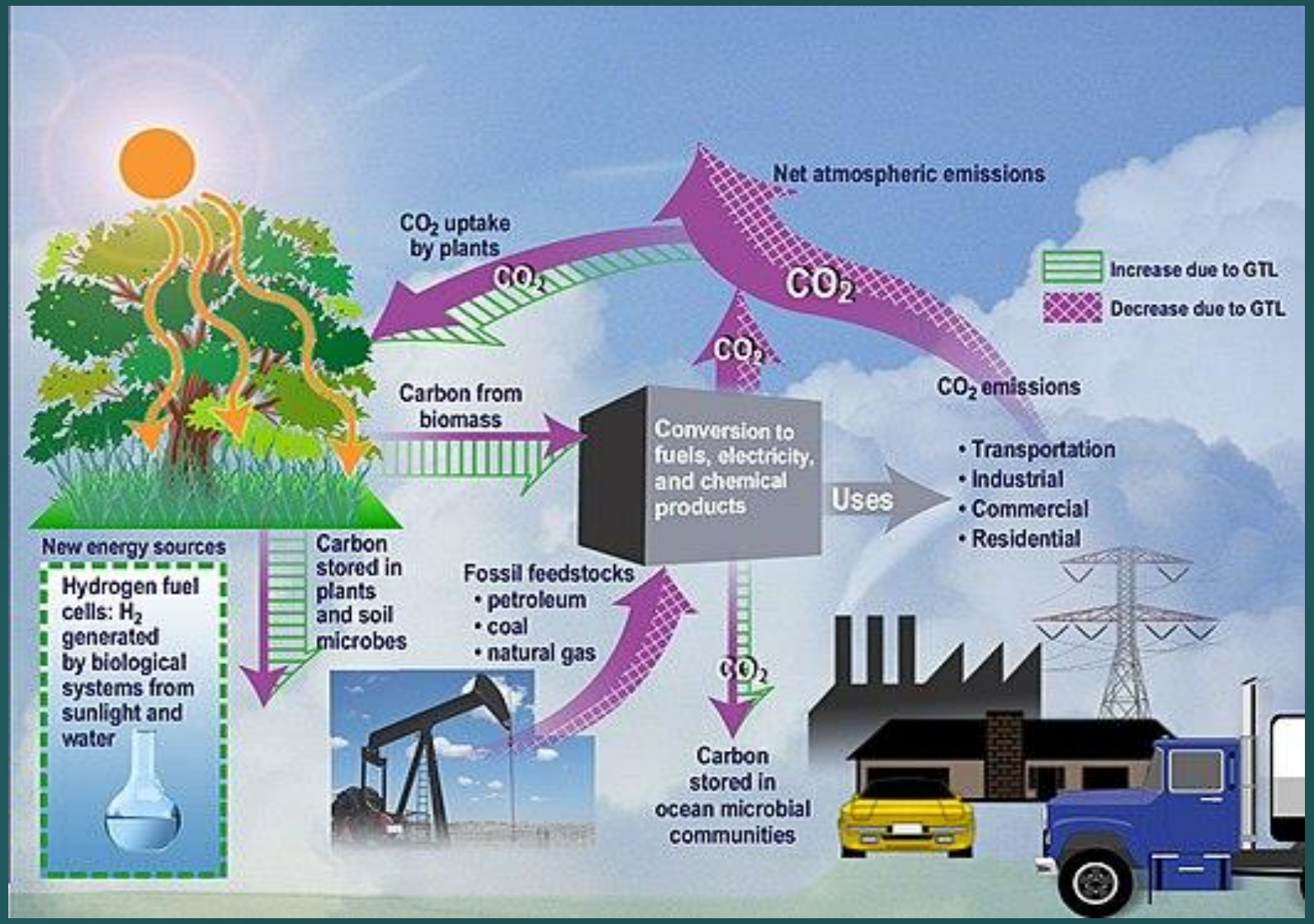
Ecological systems:
The context for species and individuals



Trophic pyramids

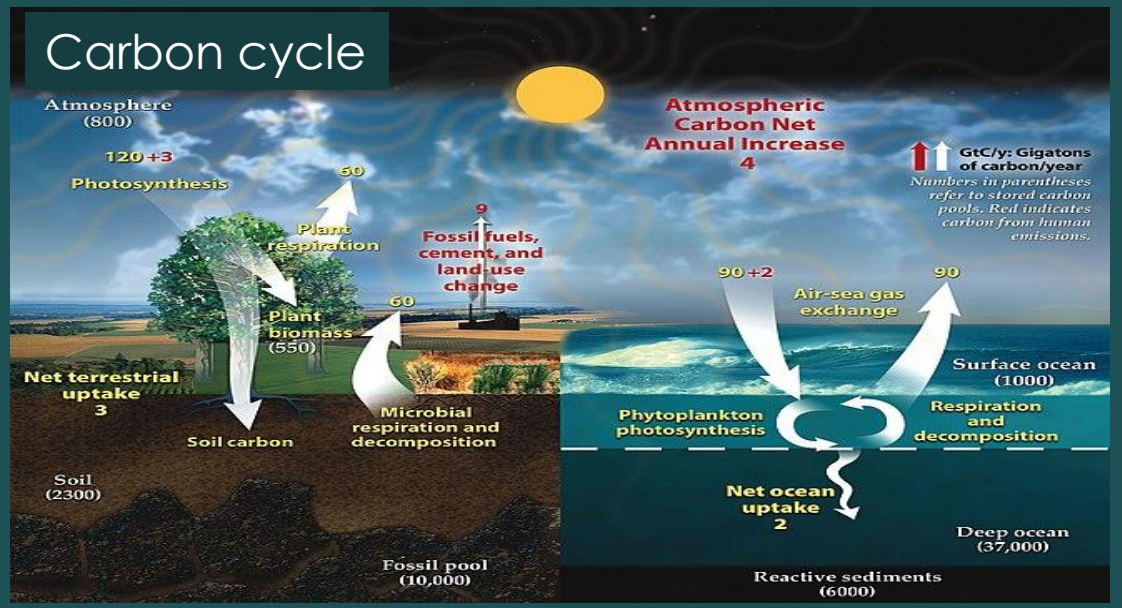
Food webs

This context provides niches that specific species can occupy

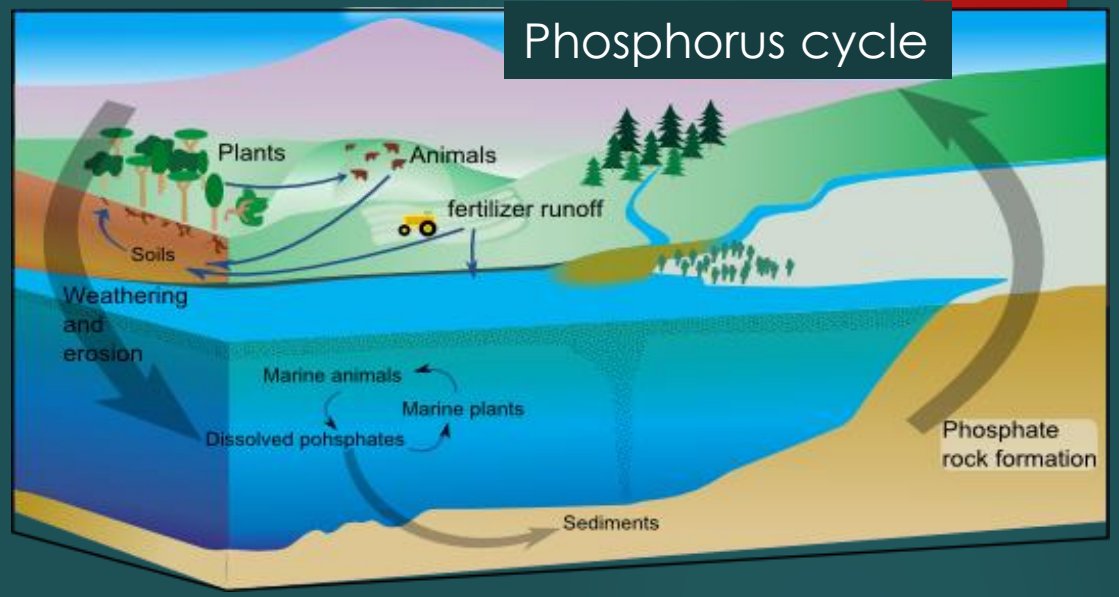


Systems ecology: interactions between factors allowing ecologies to function

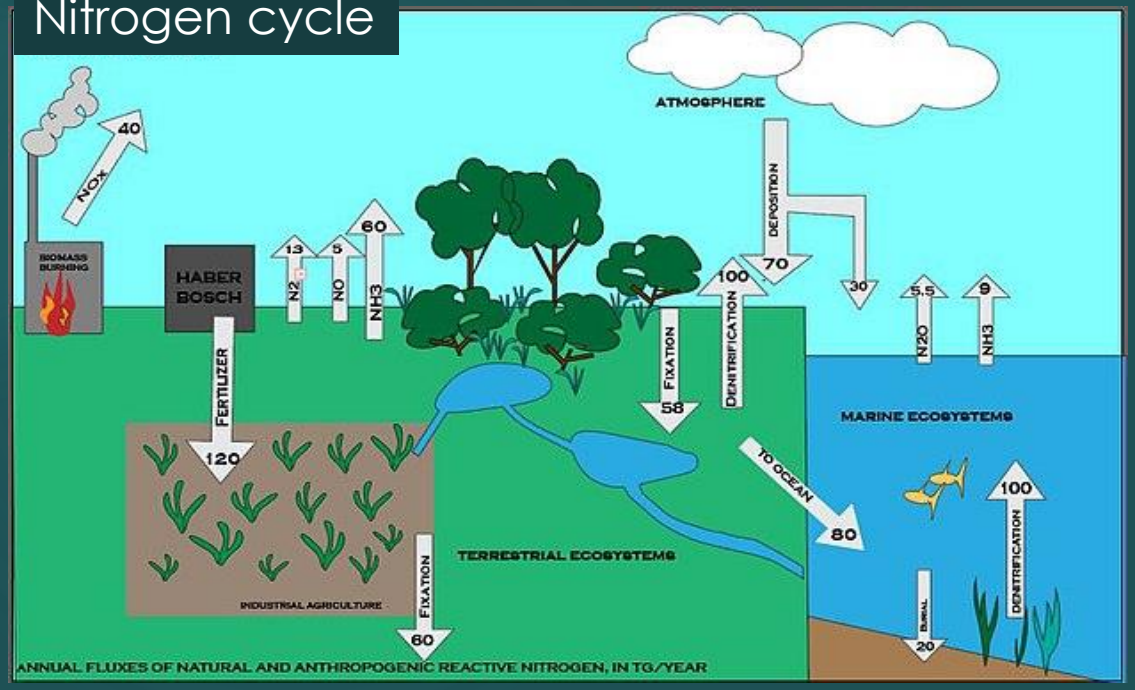
Carbon cycle



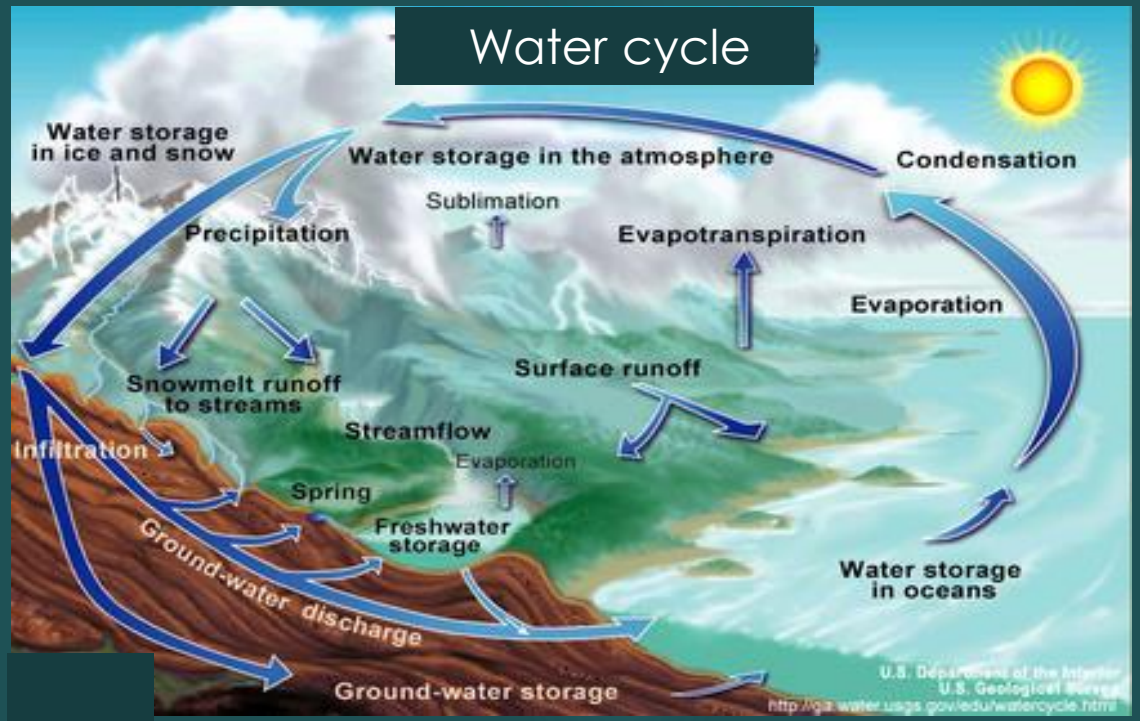
Phosphorus cycle



Nitrogen cycle



Water cycle



5. The crises facing us

- Global warming

  Floods, fires, rising seas

- Global poverty and starvation

  Humanity in need of the basics of life
  Required: sustainable development

Issues:

- Providing sufficient food: nutrition

  ➔ energy issues, right amount of water

  ➔ fighting weeds and pests, GM Crops

- Providing sufficient energy:

  ➔ Renewables, together with nuclear power

6: Taking action: values, evidence, and emotions

Values determine what we do

The basic dichotomy for individuals and organisations:

Are we working for the common good,
or to enrich ourselves/enhance our prestige?

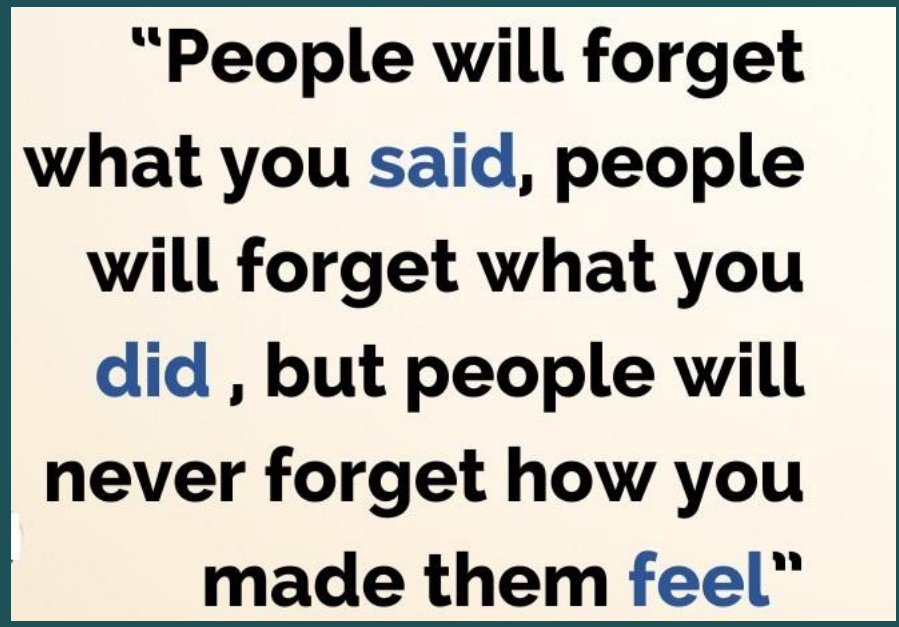
In many cases, right across the world, the latter is true

The community of physicists must be clear on its values

Taking action: dealing with people!

People's reactions are to a large degree influenced by emotions rather than rationality.

This is for good reasons: they provide fast guidance to the intellect as to how to behave – this is why the primary emotional systems have evolved.



Dealing with both the public and policy makers must take this into account. Are we acting in an arrogant way? Or sympathetically?

Taking action: Persuasion, misinformation

Determined misinformation campaigns are being run by those who profit from destroying the environment

But also by some "environmentalists",
e.g. as regards GM crops and nuclear energy.

We have to counter disinformation campaigns in an effective way, stating the scientific consensus but being persuasive as we do it.

Taking action: determination and persistence

Physicists have a significant role to play, because in the end, many of these issues are based in physics.

However the way they work out is a result of the complex interactions in physical and social modular hierarchical structures.

Taking this all into account, and acting on it as a community, is a challenging but rewarding activity demanding determination and persistence.

ACP2023 can play a useful role in this regard.