Schrödinger and Sustainbility: 70 years later

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Erwin Schrödinger (1887-1961)

- A Nobel Prize-winning (1933) Austrian physicist
- One of the founders of quantum theory
- Contributed in various fields of physics: statistical mechanics and thermodynamics, physics of dielectrics, colour theory, electrodynamics, general relativity, and cosmology, and he made several attempts to construct a unified field theory.
- In the first years of his career Schrödinger became acquainted with the ideas of quantum theory, developed in the works of Max Planck, Albert Einstein, Niels Bohr, Arnold Sommerfeld, and others.

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Erwin Schrödinger (1887-1961)

- The idea of energy as a statistical concept was a lifelong attraction for Schrödinger and he discussed it in some reports and publications.
- In January 1926, Schrödinger published the paper on wave mechanics and presented what is now known as the Schrödinger equation*.
- This paper has been universally celebrated as one of the most important achievements of the twentieth century and created a revolution in quantum mechanics and indeed of all physics and chemistry.
- Schrödinger’s cat thought experiment.

* is a partial differential equation that describes how the quantum state of a physical system changes with time

SYKE

Erwin Schrödinger (1887-1961)

- He moved to Dublin, became the Director of the School for Theoretical Physics in 1940. He became a naturalized Irish citizen in 1948, but retained his Austrian citizenship.
- **Gave famous *What is Life?* –lectures in 1943, published as a book 1944.**
- Schrödinger's lecture focused on one important question: “How can the events in space and time which take place within the spatial boundary of a living organism be accounted for by physics and chemistry?”
- Schrödinger stayed in Dublin until retiring in 1955.

Erwin Schrödinger (1887-1961)

- In 1956, he returned to Vienna.
- At an important lecture during the World Energy Conference he refused to speak on nuclear energy because of his skepticism about it and gave a philosophical lecture instead.
- During this period Schrödinger turned from mainstream quantum mechanics' definition of wave–particle duality and promoted the wave idea alone, causing much controversy.
- He paid great attention to the philosophical aspects of science, ancient and oriental philosophical concepts, ethics, and religion. He also wrote on philosophy and theoretical biology.
- He had a lifelong interest in the Vedanta philosophy of Hinduism, which influenced his speculations on consciousness.

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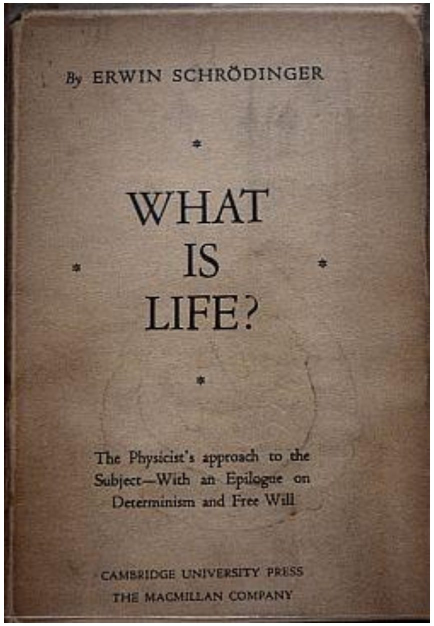
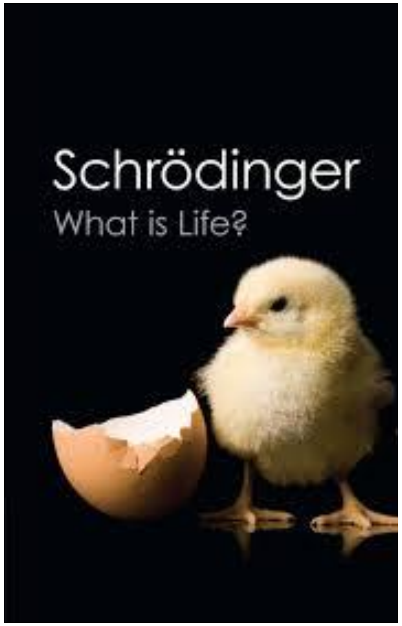
What is Life?

- The book is based on lectures delivered under the auspices of the Institute at Trinity College, Dublin, in February 1943 and published in 1944. At that time DNA was not yet accepted as the carrier of hereditary information, which only was the case after the Hershey–Chase experiment of 1952.
- Schrödinger introduced the idea of an "aperiodic crystal" that contained genetic information in its configuration of covalent chemical bonds. In the 1950s, this idea stimulated enthusiasm for discovering the genetic molecule. Although the existence of DNA had been known since 1869, its role in reproduction and its helical shape were still unknown at the time of Schrödinger's lecture.





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What is Life?

- Two fundamental processes:
  1) ”Order from order”
  2) ”Order from disorder”

1) Heredity: offspring inherited the traits of the parent, information transmitted with genes

- DNA-RNA-proteins
- Mutations
- Natural selection and adaptation

2) Less understood: Linking biology with the fundamental theorems of thermodynamics

- Metabolism
- Trophic interactions
- Food chains

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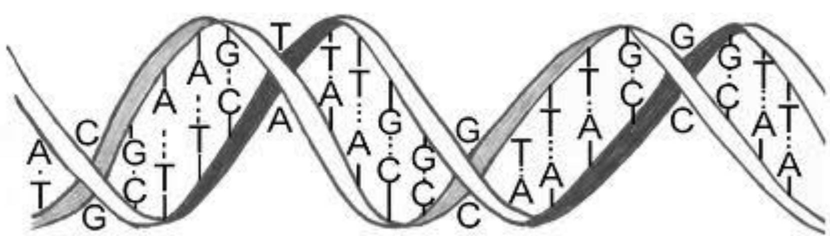
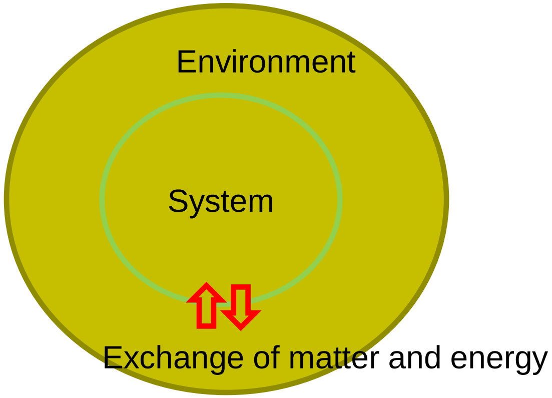
What is Life: *”Order from order”*

- Schrödinger suggested:
  - Life is based on the structure of large aperiodic solids, crystals.
  - Stability of those solids is carrier material of genetic information.
- That was later revealed to mean double-helix of DNA (Watson & Crick 1953).
- Molecular biology has expanded enormously since then.



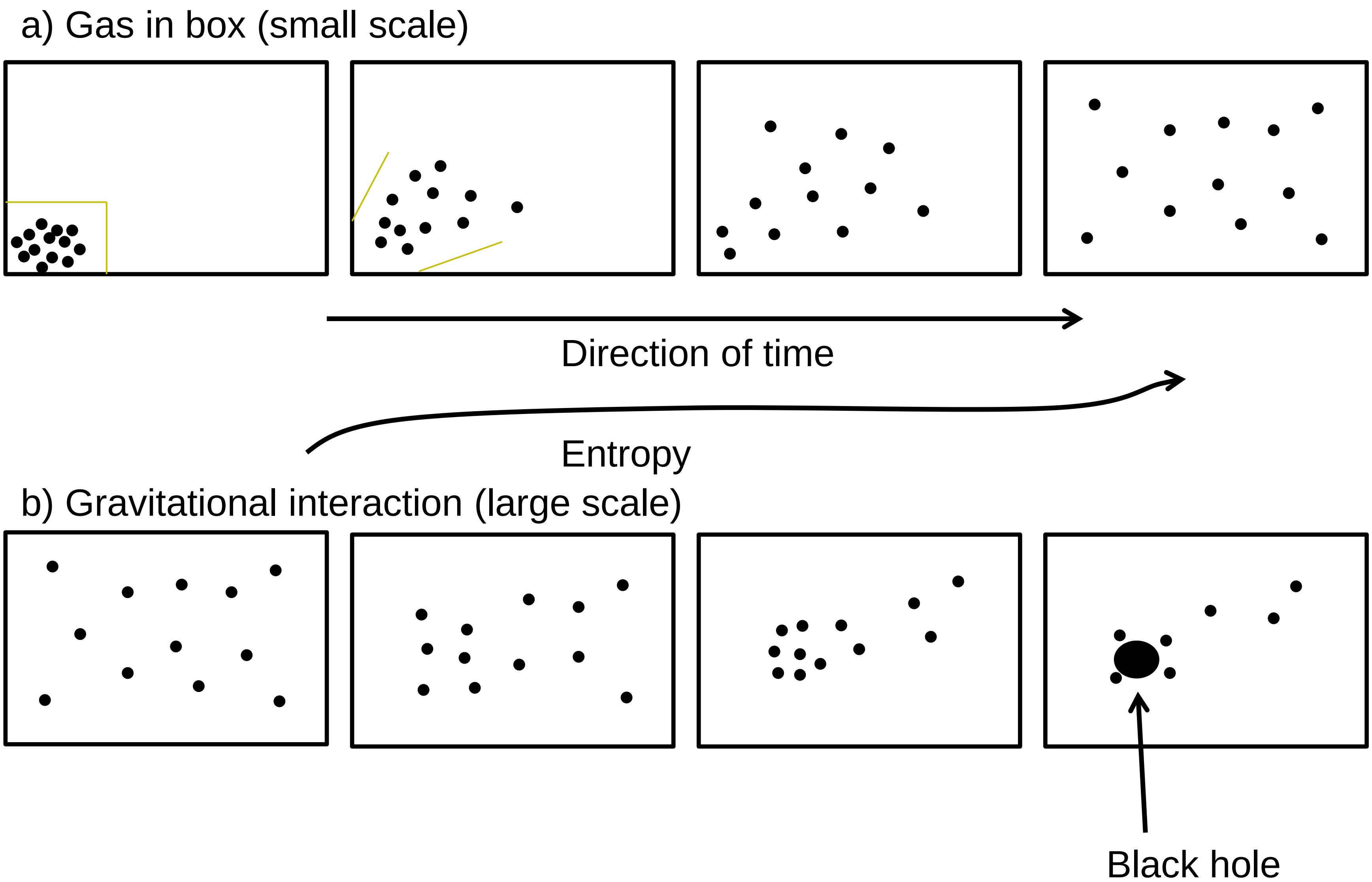
What is Life: *"Order from disorder"*

- Schrödinger thought:
  - It seemed that living systems do not obey the 2nd law of thermodynamics (i.e. entropy of isolated system increase, free energy decrease).
- For instance, plants are highly ordered structures which are synthesized from disordered atoms and molecules found in atmospheric gases and soils.
- Schrödinger's solution: non-equilibrium thermodynamics:
  - Taking high-quality energy from environment, processing it to produce within itself a more organized state.
- Fluxes of energy and matter between environment and system.



Supersystem

2nd law



Roger Penrose 2012: Cycles of time, p. 74.

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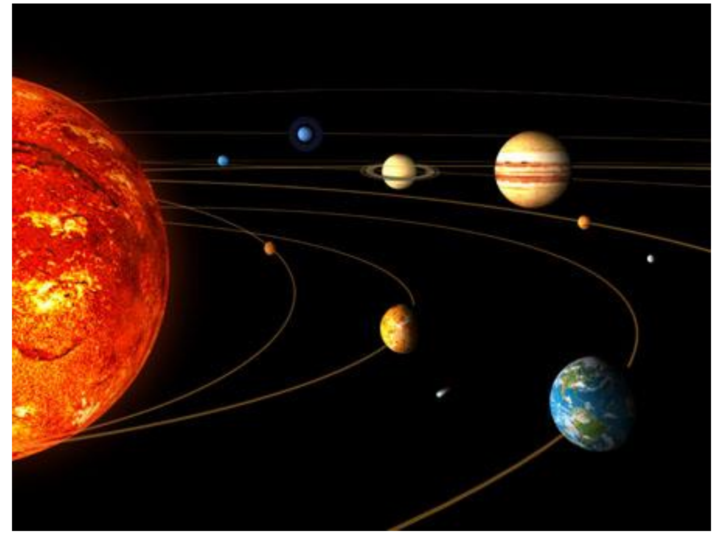
What is Life: *”Order from disorder”*



- Exergy is a central concept.
- Energy varies in its quality or capacity to do useful work. During any chemical or physical process the quality or capacity is lost.
- Exergy is a measure of the maximum capacity of an energy system to perform useful work as it proceeds to equlibrium with its surroundings.
- Living system is a far-from-equilibrium dissipative structure that maintains its local level of organisation at the expense of producing entropy in the environment.

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Schrödinger's Sustainability

- Energy efficiency & value of information based on heredity are corner stones (of ”life”)
- Scales of life:
  - We can operate in everyday's sustainability issues happily without a thought to Schrödinger's concepts
    - One can study phenomenons of ecology based e.g. on statistical basis without thinking genes or atoms.
    - One can study societies life cycle calculations of products without thinking chemical bounds and energy contents.
  - But being aware of the physical background might open new windows to look at questions or problems of sustainability from a different perspective.

    → Systems Ecological approach

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Future for Sustainability science

- I argue building upon the Schrödinger's lessons that:
  - *Lack of consistent biophysical theory has been bothering the current discussion of ecosystem services, resilience, natural capital etc.*
  - *Ecological Economics builds on these corner stones, but is either neglected or misused (or misunderstood) in many current studies.*
  - *Too much loose ground and free space in societal debate of the things: mantras of economists are repeated in media without thorough thinking and critique.*
- Sustainability science is an emerging new field of research: knowing the Schrödinger's worldview could speed up finding the new solutions
  - Exergy and information are the tools.

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Example of the relationship of information and exergy:

reradiate its energy at the lowest exergy level; that is, the ecosystem would have the coldest black body temperature.

Luvall and Holbo (1989, 1991) have measured surface temperatures of various ecosystems using a thermal infrared multispectral scanner (TIMS). Their data show one unmistakable trend, that when other variables are constant the more developed the ecosystem, the colder its surface temperature and the more degraded its reradiated energy.

TIMS data from a coniferous forest in western Oregon showed that ecosystem surface temperature varies with ecosystem maturity and type. The highest temperatures were found at a clear-cut and over a rock quarry. The coldest site, 299K, some 26K colder than the clear-cut, was a 400-year-old mature Douglas Fir forest with a three tiered plant canopy. A quarry degraded 62% of the net incoming radiation while the 400-year-old forest degraded 90%. Intermediate-aged sites fell between these extremes, increasing energy degradation with more mature or less perturbed ecosystems. These unique data sets show that ecosystems develop structure and function that degrades imposed energy gradients more effectively (Schneider & Kay, 1994).

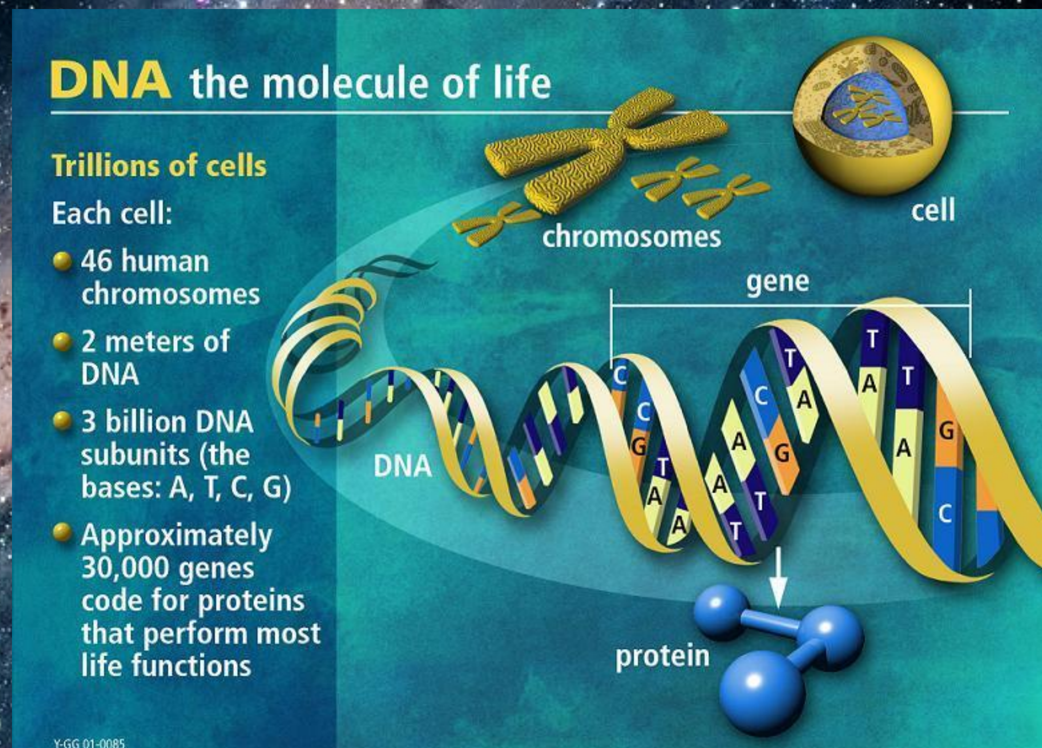
Our study of the energetics of ecosystems treats them as open systems

70 years later...

- We know the possibilities of DNA (”*information capital*”)
- We talk about bioeconomy (”*energy capital*”)
- We understand the need of resource efficiency (”*material capital*”)
- Some of us want to prioritize energy production with the expense of information (…*resulting biodiversity loss*)
- Some of us want to tag monetary values on nature’s benefits (…*what about applying ecological economics?*)

- Mimicing nature’s energy efficiency is crucial for technosystems that wish to evolve sustainably.
- Harvesting, valuing, conserving and increasing nature’s information flows is crucial for stability of coupled human-environment systems.
- ”*What is life*” remains one of the top ten unsolved questions in science.

Ecology and evolution (i.e. life) is playing with time.
Thanks for your atention!



Further reading:
Schneider & Kay 1994: Order from disorder: the thermodynamics of complexity in biology.