“There is only one science, physics. All the rest is social work.”

Some reflections on the problem of reductionism

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QUANTUM LADDER

1 m  Matter, organisms

10^{-6} m  Cells

10^{-9} m  Nuclei of cells, molecules

10^{-10} m  Atoms

10^{-14} m  Nuclei

10^{-15} m  Nucleons

10^{-40}  (Superstrings)
The problem of reductionism

• Can one level be completely reduced to a lower level? (ontological reductionism)

• (For example, cells are “nothing but” molecules. Francis Crick)
Paul Oppenheim and Hilary Putnam: "Unity of Science as a Working Hypothesis" (1958)

Key-word: Micro-reduction (from the whole to the parts)
Two arguments in favor of ontological reductionism

1) In the end ("at the bottom") everything that is happening in nature, is governed by the laws of physics.

2) Reductionism has been a success story.
Two arguments in favor of ontological reductionism

1) In the end ("at the bottom") everything that is happening in nature, is governed by the laws of physics.

   Counter-argument 1: The phenomenon of emergence.

   Counter-argument 2: Niels Bohr's idea of complementarity.

2) Reductionism has been a success story.

   Counter-argument 3: We see the end of the road.
Counter-argument 1: The phenomenon of emergence
“...if everything obeys the same fundamental laws, then the only scientists who are studying anything really fundamental are those who are working on those laws.” (Philip Anderson: "More is Different. Broken symmetry and the nature of the hierarchical structure of science", Science 4 Aug. 1972)
• “There is only one science – physics. All the rest is social work.” (James Watson)
The ultimate goal: A "theory of everything"

"However, if we do discover a complete theory [........] it would be the ultimate triumph of reason – for then we would know the mind of God."

(Conclusion of Stephen Hawking: A Brief History of Time, 1988)
"The Astonishing Hypothesis is that "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."

All thinking is no doubt nothing but physiological processes

All physiological processes are in reality nothing but biochemistry

All biochemistry is in reality nothing but pure chemistry.

All chemistry is after all really nothing but atomic physics...

All atomic physics is in fact nothing but particle physics...

All particle physics is in fact nothing but mathematics...

All mathematics is in reality nothing but thinking...
"If my mental processes are determined wholly by the motions of atoms in my brain, I have no reason to suppose that my beliefs are true ... and hence I have no reason for supposing my brain to be composed of atoms." (J. B. S. Haldane, Possible Worlds 1927)
Emergence

“At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one. Psychology is not applied biology, nor is biology applied chemistry.” (Anderson 1972)
"I heard the great evolutionist Ernst Mayr claiming 30 or 40 years ago, when he described emergence to Niels Bohr, Bohr said: "but we have that in physics as well! - physics is all emergent", but at the time, as usual, only Bohr knew what he meant.

In fact, the story of physics in the last half of the 20th century has been one of emergence – Bohr was also, as usual, basically right."

" (P. Anderson: "What is a Concensed Matter Theorist?", in Philip W. Anderson: More and Different, World Scientific 2011
Examples of emergent physical properties

• A simple atom of gold cannot be yellow and shiny and conduct electricity. Properties of gold metal have only meaning at a macroscopic scale.

• A molecule of salt is not a cube. Only a salt crystal can have cubic symmetry.

(P. Anderson: "Emergence vs. Reductionism", in Philip W. Anderson: More and Different)
Counter-argument 2: Niels Bohr's idea of complementarity

- Originally developed to solve the particle/wave dualism in quantum mechanics
- Later developed further to cover other areas, in particular as an alternative to reductionism
Niels Bohr: Virkningskvantet og naturbeskrivelsen ("The quantum of action and the description of nature", 1929)

• The example of the stick used by a man to find his way around a dark room.

• The two aspects of the stick are complementary. One aspect excludes the other.

(However, the stick as an instrument is primary, and as a physical object secondary.)
The double-slit experiment
“When one wants to clarify the meaning of the words “the position of an object”, for example an electron (relative to a given frame of reference”), one has to specify certain experiments with which one can measure the “position of the electron”: if this is not the case, the words have no meaning.” (Werner Heisenberg: “The Physical Content of Quantum Kinematics and Dynamics”, 1927)
Indeed, the finite interaction between object and measuring agencies...entails the necessity of a final renunciation of the classical ideal...and a radical revision of our attitude towards the problem of physical reality. (Bohr, Discussion with Einstein...)
Basic ideas:

• The “observer” cannot be eliminated
• There is no “God's Eye View” (or no view from nowhere)
• Some perspectives are mutually exclusive
• The everyday world perspective is prior to a theoretical perspective
Counter-argument 3:
We see the end of the road.
Starting point

- Mortality rates for most types of adult cancer are either stable or increasing
- Improvements not due to gene therapy
- It is due to
  - technological improvements that facilitate early detection
  - surgery, radiation and chemotherapy ("cut", "burn" and "poison")
- It demonstrates the defeat of the reductionist program in genetics and molecular biology
Schrödinger transformed the question from "What is life?" to "What is the physiochemical basis of heredity?"
Heredity

• Passes on a certain order from one generation to the next ("order from order").

• The genome is an "aperiodic crystal" (to be able to pass on information): "We believe a gene – or perhaps the whole chromosome fibre – to be an aperiodic solid."
• The genome contains the "code-script" for the construction of the whole organism.

• The central dogma (coined by Francis Crick):
  DNA -> RNA -> protein
The onco-gene theory

"The Schrödingerian paradigm, as played out in cancer biology, had it that there was a handful of genes, normally involved in regulating essential cell functions, that became disfuntional through, for example, mutation.[...]

... but it is reductionist in believing that all higher-level properties can be explained by lower-level properties." (Hendrickson 2011)
"Post-Schröderian Perspective"

"Genes, it was now understood, operated in context; the expression of a particular gene depended crucially on the state of other genes in its network. [...] In short, intervening in the workings of a complex nonlinear network in a targeted way did not lead to a localized change in that targeted metabolic step; it produced instead a disequilibrium for which the entire network attempted to compensate in order to restore the network to its previous state." (Hendrickson 2011)
Two kinds of law

• “order from disorder”
  - the second law of thermodynamics
  - laws based on the law of large numbers

• “order from order”
  - “Life seems to be orderly and lawful behaviour of matter, not based exclusively on its tendency to go over from order to disorder, but based partly on existing order that is kept up.”
Entropy

• Statistical interpretation:
  \[ S = k \ln W \]
  \( W = \text{thermodynamic probability} \)
  entropy = disorder

• Basic idea: Disorder has higher probability than order
• Schrödinger:
  \[ \text{negentropy} = \text{order} \]

• Life “feeds on” negentropy.
• “What I wish to make clear in this last chapter is, in short, that from all we have learnt about the structure of living matter, we must be prepared to find it working in a manner that cannot be reduced to the ordinary laws of physics.” (Schrödinger 1944)