

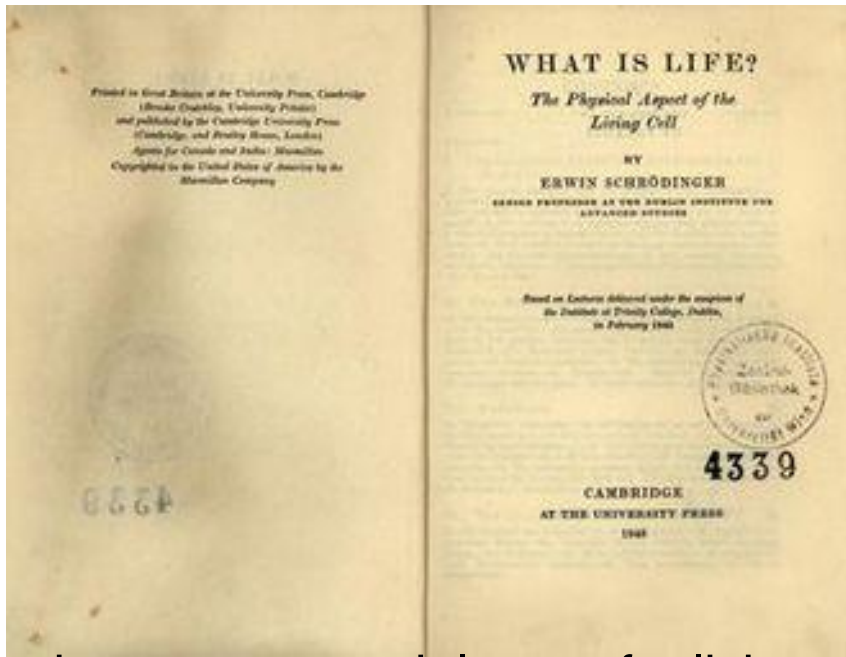
Evolution of complexity in biology and beyond

Learning - Evolution - Thermodynamics

Evolution of Complexity from the Statistical Physics
Perspective

June 29-July 2, 2022

Yerevan



- the most essential part of a living cell - the chromosome fiber - may suitably be called an aperiodic crystal
- 'It [a living organism] feeds upon negative entropy', attracting, as it were, a stream of negative entropy upon itself, to compensate the entropy increase it produces by living and thus to maintain itself on a stationary and fairly low entropy level.

...living matter, while not eluding the "laws of physics" as established up to date, is likely to involve "other laws of physics" hitherto unknown, which however, once they have been revealed, will form just as integral a part of science as the former.

Anderson PW. More is different. Science. 1972

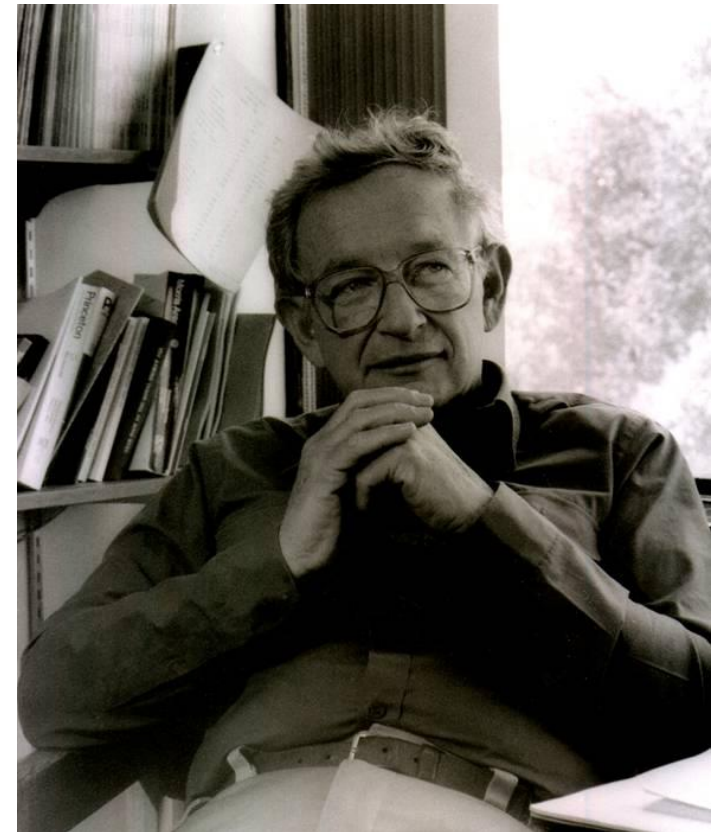
Broken symmetry and the nature of the hierarchical structure of science.

The elementary entities of Science X obey the laws of science Y:

X	Y
solid state or many-body physics	elementary particle physics
chemistry	many-body physics
molecular biology	chemistry
cell biology	molecular biology
⋮	⋮
⋮	⋮
⋮	⋮
psychology	physiology
social sciences	psychology

FITZGERALD: The rich are different from us.

HEMINGWAY: Yes, they have more money.



???

Laughlin RB, Pines D. The theory of everything. PNAS 2000

$$i\hbar \frac{\partial}{\partial t} |\Psi\rangle = \mathcal{H} |\Psi\rangle \quad (1)$$

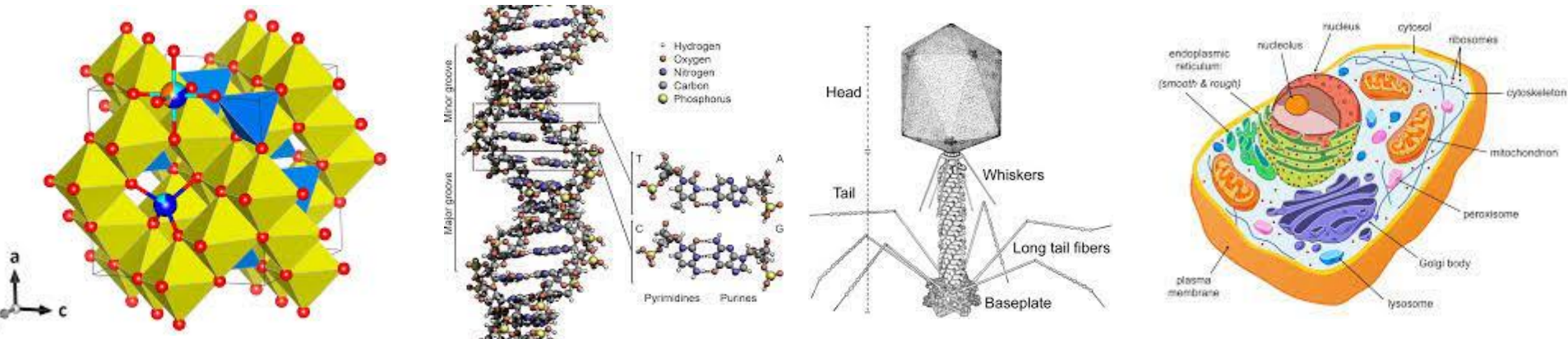
$$\mathcal{H} = -\sum_j^{N_e} \frac{\hbar^2}{2m} \nabla_j^2 - \sum_\alpha^{N_i} \frac{\hbar^2}{2M_\alpha} \nabla_\alpha^2 - \sum_j^{N_e} \sum_\alpha^{N_i} \frac{Z_\alpha e^2}{|\vec{r}_j - \vec{R}_\alpha|} + \sum_{j \ll k}^{N_e} \frac{e^2}{|\vec{r}_j - \vec{r}_k|} + \sum_{\alpha \ll \beta}^{N_j} \frac{Z_\alpha Z_\beta e^2}{|\vec{R}_\alpha - \vec{r}_\beta|}. \quad (2)$$

Eqs. [1](#) and [2](#) are, for all practical purposes, the Theory of Everything for our everyday world. However, it is obvious glancing through this list that the Theory of Everything is not even remotely a theory of every thing.

Laughlin RB, Pines D, Schmalian J, Stojkovic BP, Wolynes P. The middle way. Proc Natl Acad Sci U S A. 2000

Mesoscopic organization in soft, hard, and biological matter is examined in the context of our present understanding of the principles responsible for emergent organized behavior (crystallinity, ferromagnetism, superconductivity, etc.) at long wavelengths in very large aggregations of particles. Particular attention is paid to the **possibility that as-yet-undiscovered organizing principles might be at work at the mesoscopic scale, intermediate between atomic and macroscopic dimensions**, and the implications of their discovery for biology and the physical sciences. The search for the existence and universality of such rules, the proof or disproof of organizing principles appropriate to the mesoscopic domain, is called the middle way.

Evolution of complexity



complexity

Seth Lloyd, "Measures of complexity: a non-exhaustive list" – 40 different definitions

"I know it when I see it"

Justice Potter Stuart on definition of obscenity (1964)

Evolution of complexity, multilevel learning and thermodynamics

- Wolf YI, Katsnelson MI, Koonin EV. **Physical foundations of biological complexity.** *Proc Natl Acad Sci U S A.* 2018 Sep 11;115(37):E8678-E8687
- Vanchurin V. 2020. **The World as a Neural Network.** *Entropy* 22(11):1210
- Vanchurin V, Wolf YI, Katsnelson MI, Koonin EV. **Toward a theory of evolution as multilevel learning.** *Proc Natl Acad Sci U S A.* 2022 Feb 8;119(6):e2120037119.
- Vanchurin V, Wolf YI, Koonin EV. Katsnelson MI. **Thermodynamics of evolution and the origin of life.** *Proc Natl Acad Sci U S A.* 2022 Feb 8;119(6):e2120042119

Frustration: different learning objectives at different levels

From frustrated states to complexity

