Statistical Physics in Biology

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Statistical Physics in Biology is the study of how to apply either the methodology or the physical description in statistical physics to solve biological problems. It emphasizes on the mechanism of the emergent properties of biological systems as physically evolving systems, and often overlaps with the studies of active matter and bio-informatics.

1 What does it study?

There are two types of studies of statistical physics in biology. One is drawing analogies from statistical physics to biological systems; the other one is researching the underlying physical constraints or driving force for biological systems.

The first type can be further divided into two subcategories . One is applying common mathematical techniques to biological questions, e.g. using diffusion equations in population genetics, applying stochastic mechanics to self-assembly networks such as the swarm of honeybees and the diversity in ecosystems, as well as employing spin glass models in neuron networks and protein folding. The second subcategory is developing precise analogies that incorporate physics concepts to biological phenomena, e.g. introducing the concept of entropy in bio-informatics [1, 2]. Sometimes the two methods combine, e.g., using both the concept and mathematical tools provided by the statistical physics to link "microscopic" genomic sequence information and"mesoscopic" phenotypes to "macroscopic" fitness and evolution [3].

The second type (which studies underlying physical constraints or driving force for biological systems), often applies non-equilibrium thermodynamics and explains the evolution and other biological phenomena involving energy exchange. For example, England lab in MIT has derived an extension of the 2nd Law of Thermodynamics to show that the growth rate and durability of self-replicators (e.g. bacteria) "set hard constraints on the minimum amount of chemical fuel required for growth" in 2013. Since then, they have been attempting to "determine the sufficient physical conditions for life-like physical properties to emerge and persist in settings where they are initially absent" [4].

2 What techniques/knowledge does it use?

The main work in this field is theoretical analysis and numerical simulation, sometimes cooperating with biological experimental groups. Notable analytic approaches include hydrodynamics, kinetic theory, non-equilibrium thermodynamics, phase transitions, and stochastic mechanics. Numerical simulations involve self-propelled-particles models [5], toy-chemistry models [4] etc. that simulate the evolution of the system and test the theoretical hypotheses.

3 What are the applications/contributions?

Statistical physics analyses all particles as particles no matter they are in living organisms or not. This point of view helps to reveal the physics behind the functions and evolution of different biological organisms. Also, the methodology in statistical physics focuses on the collective behaviour rather than individual states, which often reveals novel ways to solve biological problems by looking into the key parameters that affect the configurations of the systems.

Apart from helping us better understand how biological systems and evolution work, it also provides solutions to engineer who seeks to mimic the architecture of life, as well as aiding the discovery of life traces in the space.

4 Personal Comments

The attractive things in this area are:

- I like drawing analogies among things and noticing the difference between them. I am also a fan of finding unifying theories haha!
- It seems that I can fit my interest in evolution, neuroscience, quantum biology, biomechanics all with statistical physics in biology, which is fantastic!
- The methodology learned in statistical physics also has wide applications in economics or finance analysis, which means it may help me be in good shape in the job market.

The concerns are:

- stochastic mechanics are famous for its difficulties.....I am not sure whether I am smart or persistent enough...
- I will mainly be sitting in front of the computers I suppose....which is not very healthy....
- It may involve quite a lot of programming, which is also not my strength and I am easy to get irritated when debugging.....

5 Further Readings

Articles / Lectures:

- *Non-equilibrium statistical mechanics*: http://wwwf.imperial.ac.uk/~pruess/publications/noneq.pdf
- http://courses.physics.ucsd.edu/2013/Fall/physics210b/LECTURES/STOCHASTIC.pdf
- *Brownian motion: a paradigm of soft matter and biological physics*: https://onlinelibrary.wiley.com/doi/abs/10.1002/andp.200410132
- *An introduction to the statistical physics of active matter: motility-induced phase separation and the "generic instability of active gels*: https://link.springer.com/content/pdf/10.1140%2Fepjst%2Fe2016-60084-6.pdf
- *The statistical physics of active matter: from self-catalytic colloids to living cells*: https://arxiv.org/pdf/1708.08652.pdf
- *The contribution of statistical physics to evolutionary biology*: https://arxiv.org/pdf/1104.2854.pdf
- *A walk in the statistical mechanical formulation of neural networks*: https://arxiv.org/pdf/1407.5300.pdf
- Lecture videos *Statistical physics of active matter* by Sriram Ramaswamy: https://www.youtube.com/user/ICTStalks/search?query=statistical+physics++active+matter
- Lecture notes *Statistical Physics in Biology* by Mehran Kardar & Leonid Mirny :https://ocw.mit.edu/courses/physics/8-592j-statistical-physics-in-biology-spring-2011/
- Lecture notes *Statistical Physics of Biology Information and Complexity*: http://guava.physics.uiuc.edu/~nigel/courses/598BIO/
- Lecture notes *Statistical Physics and Protein Folding*: https://www.worldscientific.com/worldscibooks/10.1142/5741
- A blog run by Daniel M. Zuckerman on Statistical Biophysics: http://statisticalbiophysicsblog.org/

Laboratories :

- England Group for statistical physics in early life evolution at MIT, USA: https://www.englandlab.com/

- William Bialek for theoretical biophysics and neurobiology at Princeton University, USA: https://lsi.princeton.edu/faculty/william-bialek
- Philip Nelson lab for physical models in biology at University of Pennsylvania, USA: http://www.physics.upenn.edu/~pcn/
- Broedersz Group for theoretical statistical and biological physics group at the University of Munich, Germany: http://www.theorie.physik.uni-muenchen.de/lsfrey/group_broedersz/index.html
- Lssig Group for statistical physics and quantitative biology at the University of Cologne, Germany: http://www.thp.uni-koeln.de/~lassig/index.html

References

[1] Giorgio Parisi. Statistical physics and biology. *Physics World*, 6(9):42, 1993.

[2] Harold P. de Vladar and Nick H. Barton. The contribution of statistical physics to evolutionary biology. *Trends in Ecology & Evolution*, 26(8):424–432, 2011.

[3] Michael Lassig. Statistical physics and quantitative biology. http://www.thp.uni-koeln.de/~lassig/research.html, 2018. Date accessed: 2018-04-05.

[4] Jeremy England. England lab mit physics. https://www.englandlab.com/, 2018. Date accessed: 2018-04-05.

[5] WikiPedia. Self-propelled particles. https://en.wikipedia.org/wiki/Self-propelled_particles, 2018. Date accessed: 2018-04-05.