This is an electronic reprint of the original article. This reprint may differ from the original in pagination and typographic detail.

Author(s): Annila, Arto; Kolehmainen, Erkki

Title: On the divide between animate and inanimate

Year: 2015

Version:

Please cite the original version:
Annila, A., & Kolehmainen, E. (2015). On the divide between animate and inanimate. Journal of Systems Chemistry, 6(2). https://doi.org/10.1186/s13322-015-0008-8

All material supplied via JYX is protected by copyright and other intellectual property rights, and duplication or sale of all or part of any of the repository collections is not permitted, except that material may be duplicated by you for your research use or educational purposes in electronic or print form. You must obtain permission for any other use. Electronic or print copies may not be offered, whether for sale or otherwise to anyone who is not an authorised user.
Vitalism was abandoned already for a long time ago, yet the impression that animate beings differ in some fundamental way from inanimate objects continues to thrive. Here, we argue that scale free patterns, found throughout nature, present convincing evidence that this demarcation is only imaginary. Therefore, all systems ought to be regarded alike, i.e., all are consuming free energy in least time. This way evolutionary processes can be understood as a series of changes from one state to another, so that flows of energy themselves naturally select those ways and means, such as species and societies or gadgets and galaxies to consume free energy in the least time in quest of attaining thermodynamic balance in respective surroundings. This holistic worldview, albeit an accurate account of nature, was shelved soon after its advent at the turn of the 18th century, because the general tenet did not meet that time expectations of a deterministic law, but now it is time to reconsider the old universal imperative against observations rather than expectations.

Keywords: Free energy, Life, Non-determinism, The principle of least action, The second law of thermodynamics, Scale invariant

Background

The recent perspective on The nature and mathematical basis for material stability in the chemical and biological worlds by Robert Pascal and Addy Pross elaborates on conceptual conundrums that hinder us from relating animate to inanimate [1]. The authors recap these theoretical problems in the perennial question, how life could have emerged from inanimate matter. Moreover, Pascal and Pross are alarmed that biology, as a discipline, has by today grown apart from physical sciences, although chemistry did become biology on this planet some 3.5 to 4 billion years ago. Hence, the logical conclusion is that all disciples must have a common conceptual basis.

We have hardly anything to add on this sharp analysis of the status quo. Yet, we wish to emphasize that only by convention we refer to some systems as living while others as nonliving, but nature itself does not make the divide: scale free patterns are ubiquitous [2-10]. Throughout nature are found skewed, nearly log-normal distributions that accumulate along sigmoid curves, and hence appear on log-log scales mostly as straight lines, i.e., comply with power laws [11,12]. These patterns share the same mathematical form, only parameters differ from one system to another.

For example, lengths of genes distribute in the same skew manner as lengths of words. Animal and plant populations, irrespective of a species, spread out on terrestrial and marine environments in the same manner as economic wealth, irrespective of assets, spreads out in diverse societies. Likewise, chemical reactions and economic transactions proceed along sigmoid curves toward stationary cycles such as citric acid cycle in a cell and annual cycles of production. Also a cyclone whirls in a temperature gradient in the same way as a galaxy spirals in the universal density. These logarithmic spirals appear also in many other familiar forms such as shells, cones and inflorescences.

Moreover, ecological succession advances in the same way as technological progress, that is, by punctuating from one innovation to another along a sigmoid curve. Production of goods branches out just as a phylogenetic tree of species fans out. So does also an electric discharge disperse in a medium, for instance, lighting in the air. Furthermore, neural activity recorded from cortex follows a power law just as seismic activity recorded from Earth’s mantle. A metabolic network across a cell displays the same power-law degree distribution of intersections as the nodes of a transportation network across
a city or the communication network World Wide Web
across the Globe as well as the network of galaxies
across the Universe. These universal patterns present
compelling evidence that there is a natural law that en-
compasses everything.

The law of nature
The basic law of nature is no mystery. It says that energy
differences of any kind, i.e., free energy of any kind will
be consumed in least time when a system of any kind
moves from one state to another [12-15]. The opening
words of Principia address the same relation between
forces and motion: Rational Mechanics will be the sci-
ence of motions resulting from any forces whatsoever and
of the forces required to produce any motions, accurately
proposed and demonstrated [16]. Subsequently Newton
produces the renowned equality \( F = d\mathbf{p} \) between the
force \( F \) and the change in momentum \( \mathbf{p} \), i.e., the change
in the course. No system has any choice but to move
along the resultant force, i.e., along the path where free
energy is consumed in least time.

Also Carnot recognizes the universality without divide
between animate and inanimate [17]: *All substances in
nature can be employed for the production of impelling
power*. Power \( P \) equals the consumption of free energy.
Since \( P = F \cdot v = dp, v = d2K \), no energy in motion with
velocity \( v \), i.e., kinetic energy \( 2K \), has any option but to
direct along the steepest gradient on the energy land-
scape, i.e., along the least-time path.

For example, a brook will vary its path, and this flow
of energy will all by itself, i.e., naturally, select the stee-
pest descent to run down the hill slope as soon as pos-
sible. Conversely, any rivulet cannot but drain dry when
the flow finds a faster way to consume gravitational po-
tential. According to this tenet also an animal population
will vary its ways of making living, and the associated
flows of energy will themselves naturally select among
alternatives, e.g., genetic, epigenetic, behavioral mecha-
nisms, or any other function that facilitates the least-
time free energy consumption. Conversely, no species
has any freedom but to adapt or perish, when more ef-
fective consumers of a common free energy reservoir
come around. These courses toward thermodynamic
balance with superior surroundings are not unlikely pro-
cesses, but natural for all systems. It is only a trivial
mathematical exercise to show that the least-time im-
perative, in the form of equation of motion, gives rise to
the scale free patterns [12]. Of course, these patterns
have been recognized and modeled by various mathem-
atical functions already for a long time, however, the
insight that the scale free patterns result from the least-
time free energy consumption has been overlooked.

As Pross and Pascal point out, Darwin’s tenet is only a
catching narrative without a firm mathematical form. In
contrast the universal imperative of least-time free en-
ergy consumption as given by Newton’s second law of
motion, Maupertuis’ principle of least action or Carnot’s
the second law of thermodynamics can be rigorously an-
alyzed [18,19]. These three forms are, in fact, equivalent
to each other. Specifically, Newton’s second law of
motion can be proven identical to Carnot’s second law of
thermodynamics. Recalling that \( \mathbf{v} = d\mathbf{x} \) and \( 2K = \mathbf{p} \cdot \mathbf{v} = TS \),
the force \( \mathbf{F} = d\mathbf{p} = d_s2K = Td_sS = dS_Q \) is equated with
temperature \( T \) multiplied by the change in entropy \( dS \)
along the piece of path \( dx \), which, in turn, is caused by the
change in energy \( dQ \) along \( dx \). The mathematical equiva-
ence leaves us without any options but to conclude that
evolutionary courses advance along the direction of result-
ant force. This path of least-time free energy consumption
is, in turn, equivalent to the path of maximal rate of en-
tropy increase. However, the mathematical formalism does
not imply determinism. On the contrary, evolutionary
courses are inherently intractable, because the driving
forces are consumed by motions [20]. In other words, the
net force keep changing hand in hand with changes in
motion, i.e., with evolution.

It is worth emphasizing that the standard way to omit
the change in mass \( dm \), equal to energy \( dE = \frac{dmc^2}{2} \) dissi-
pated to the vacuum characterized \( c^2 \), from the complete
form \( \mathbf{F} = \mathbf{d} \mathbf{p} = m \mathbf{a} + \mathbf{d} \mathbf{q} \), where \( \mathbf{a} = \mathbf{d} \mathbf{v} \), deprives us
from understanding any change from one state to an-
other, i.e., evolution. Not even a simple chemical reac-
tion can be understood without dissipation, and hence
the textbook thermodynamics and kinetics appear as
incongruent. In reality no kinetics runs a reaction, but
kinetics is a manifestation the least-time consumption
of free energy. Likewise, conceptual conundrums will arise,
when entropy is mistaken for a measure of disorder, i.e.,
incoherence, instead of appreciating it as a sum of both
bound and free forms of energy. At the maximum en-
tropy state of a thermodynamic balance all energy is
bound, since all free energy has been consumed.

Protein folding, for instance, is obviously not deter-
mined by an amino acid sequence alone, but depends
also on dissipation to the surroundings whose proper-
ties, temperature, \( pH \), ionic strength, chaperons, etc.
have a say on the outcome [21]. Therefore, many a
biologist rightfully regards the standard deterministic or
statistical or probabilistic forms of physics as insufficient
to explain life. Conversely, many a physicist shuns the
old but accurate dissipative equation of motion, because
it cannot be solved. The trouble is not complexity; the
trouble is that motion itself affects its driving forces.
Hence, evolutionary paths are intractable, but not arbi-
trary [20]. But isn’t this non-determinism, accompanied
with a sense of direction, precisely an outward charac-
teristic of nature? Thus, what cannot be eschew’d must
be embrac’d.
**Conclusion**

Newton’s, Maupertuis’ and Carnot’s understanding of natural processes across all scales was once as a breathtaking theory as it is today. What the pioneers reasoned complies with reality, and hence with common sense, but not with expectations of a deterministic law. Later, when discrepancy between the looked-for clockwork idealism and reality grew indisputable, imperfect deterministic interpretations of the pioneers’ original prints were not reconsidered, but science went on with disciplinary specialization. As a result, today we find many approximate mathematical models of nature to mimic many a data but to provide only little understanding of underlying causes. Hence, we should return to the exact, albeit intractable evolutionary equation to gain complete comprehension of nature.

Every time in the past when our delusions about uniqueness and particularity have narrowed, our worldview has widened toward entirety. By the same token, we should no longer imagine that animate would be qualitatively distinct from inanimate. Amazing diversity and awesome complexity in mechanistic details, which have accumulated over eons, should no longer distract us from seeing that both simple and sophisticated systems follow the universal principle of least-time free energy consumption.

**Author details**

1. Department of Physics, FI-00014 University of Helsinki, Helsinki, Finland.
2. Institute of Biotechnology, FI-00014 University of Helsinki, Helsinki, Finland.
3. Department of Biosciences, FI-00014 University of Helsinki, Helsinki, Finland.
4. Department of Chemistry, FI-40014 University of Jyväskylä, Jyväskylä, Finland.

Received: 3 September 2014 Accepted: 3 February 2015
Published online: 19 February 2015

**References**

1. Pascal R, Pross P. The nature and mathematical basis for material stability in the chemical and biological worlds. J Syst Chem. 2014;5:3. doi:10.1186/1759-2208-5-3.
2. Kaptyn JC. Skew frequency curves in biology and statistics. Astronomical Laboratory, Noordhoff: Groningen; 1903.
3. Pareto V. Manuale di economia politica (Manual of political economy). Milano: Società Editrice Libraria; 1906 [1971, translation by Page AN, Kelley AM].
4. Gaddum JH. Lognormal distributions. Nature. 1945;156:463–6.
5. Zipf GK. Human behavior and the principle of least effort. Reading, MA: Addison-Wesley; 1949.
6. Barabási A-L, Albert R. Emergence of scaling in random networks. Science. 1999;286:509–12.
7. Bejan A. Shape and structure, from engineering to nature. Cambridge, UK: Cambridge University Press; 2000.
8. Sornette D. Critical Phenomena in Natural Sciences. Berlin: Springer; 2006.
9. Clauset A, Shalizi CR, Newman MEJ. Power-law distributions in empirical data. SIAM Rev. 2009;51:661–703 (arXiv:0710.1092).
10. Limpert E, Stahel WA, Abbt M. Log-normal distributions. Nature. 1995;156:463–6.
11. Zipf GK. Human behaviour and the principle of least effort. Reading, MA: Addison-Wesley; 1949.
12. Barabási A-L, Albert R. Emergence of scaling in random networks. Science. 1999;286:509–12.
13. Bejan A. Shape and structure, from engineering to nature. Cambridge, UK: Cambridge University Press; 2000.
14. Sharma V, Annila A. Natural process – Natural selection. Biophys Chem. 2007;127:123–8.
15. Kaila VRI, Annila A. Natural selection for least action. Proc R Soc A. 2008;464:3055–70.
16. Newton I. The Mathematical Principles of Natural Philosophy. Translated by Motte A; 1729.
17. Carnot S. Reflections on the motive power of heat. Translated by Thurston RH. New York, NY: John Wiley & Sons; 1897.
18. Annila A, Annila E. Why did life emerge? Int J Astrobol. 2008;7:293–300.
19. Annila A, Salthe S. Physical foundations of evolutionary theory. J Non-equil Thermodyn. 2010;35:301–21.
20. Annila A, Salthe S. On intractable tracks. Physics Essays. 2012;25:232–7.
21. Sharma V, Kaila VRI, Annila A. Protein folding as an evolutionary process. Physica A. 2009;388:851–62.

Open access provides opportunities to our colleagues in other parts of the globe, by allowing anyone to view the content free of charge.