Review of: "Thermodynamics, Infodynamics and Emergence"

Stephen Mann[1]

1 University of Barcelona

Potential competing interests: No potential competing interests to declare.

General comments

I was excited to read this article because I have been looking for a clear and comprehensive overview of these issues for a while now. The article is somewhat informative, but I think it could be improved by clarifying some of the text in order to make the issues more accessible to a non-expert audience. I want to engage with the content but I find it very difficult to understand due to the confusing ordering of ideas and the obscurity of some concepts. I have listed the most significant of my suggested changes below in reference to the corresponding sections of the article. Here are some general suggestions:

- The article needs a simple worked example with measured quantities. Too often the terms ΔF and $\Delta \Phi$ are referred to without being related to actual numbers in examples. Maybe a simple example at the beginning could be continuously referred back to, in order to help us understand how all these different concepts interact.
- There's a lot of unusual (and inconsistent) capitalisation of words. This has the potential to be confusing because it's not clear what is the special status of capitalised words. "Energy" is not usually capitalised in physics. The phrase "Fundamental Physical Forces of Nature", and the listed forces, don't seem to need to be capitalised. If you just want to emphasise certain words, bold formatting works fine. I would aim for a consistent style in order to help the reader.
- A lot of terms are introduced without being defined. I've listed the most important of these in my specific comments.

Introduction

Energy

- "We recognize the following forms of Energy" -- are these the only forms of energy, or just the ones your article will focus on?
- Is inertia really a fundamental physical force? Usually it's just the other four that are listed.
- "Mechanical Energy - Kinetic Energy energy derived from inertia and gravitational forces" is this a heading? It ends without a full stop; the word "energy" is repeated; it's not clear whether mechanical energy is supposed to be synonymous with kinetic energy.
- You list "Heat" under "Nuclear Energy", but heat is usually described in terms of temperature differential, which in turn is defined in terms of the kinetic energy of particles (e.g. https://www.sciencelearn.org.nz/resources/750-heat-energy)
- "Dark Energy": I wouldn't include this in the list since it looks like you're not going to discuss it in the rest of the article.

- "Thermodynamics has been dealing traditionally with systems at equilibrium or near equilibrium" -- could you define equilibrium here?
- "Thermodynamics of open systems, that are far from equilibrium, and experiencing irreversible processes, are much less known" -- do you mean less well known to the public? Or unknown to science? Maybe "much less understood" would work better.
- "Our knowledge of thermodynamics can be summarized in their laws." -- should be "summarized in its laws".

Laws of Thermodynamics

"The second law of thermodynamics says that some things can't be undone after they are done. This indicates that entropy is real. It states that, in an isolated system, entropy can increase but cannot decrease." -- We have no reason so far to think entropy is not real (indeed, you've already defined it in terms of energy lost to surroundings), so I would delete the sentence "This indicates that entropy is real" because it's confusing.

Dissipative systems

- "A proposed law or rule of irreversible thermodynamics..." Is irreversible thermodynamics different from regular thermodynamics?
- "a structure of minimum dissipation" -- what does this mean?

Free Energy

"Energy can or cannot be used to produce work." -- I think "might or might not" is what you want to say here.

Helmholtz Free Energy

- You introduce the thermodynamic notion of entropy and immediately relate it to the information-theoretic notion. These are usually distinguished, so it would help to explain on what grounds you are identifying them with each other (or at least to highlight that it is unusual to consider them synonymous).
- "the actual pulling power the locomotive might expert..." -- I guess you mean "might exert" here.
- "Free energy also provides a necessary condition for processes such as chemical reactions that may occur under these conditions." -- Under what conditions? It's not clear what you mean.
- "In thermodynamics transformation of order into disorder is what defines increase of entropy." -- What are order and disorder here? Are they formally defined?

Endergonic processes

- You have a diagram referencing "Gibbs Free Energy" but you haven't introduced this concept yet. Could you introduce it before using this diagram?
- "These processes may produce negative entropy as they absorb heat or other kinds of energy from the environment." -- I don't really know what negative entropy is yet, nor how it can be produced.

Potential Energy

You are missing a full stop in the final sentence of this section.

Biological Energy; Social Energy; Cognitive energy

These sections are too short and broad to be really adding anything here. I would stick to focusing on out-of-equilibrium systems, which I assume is what the core of the article is about.

Information

- "Chemical information inherent in interactions between different types of matter." -- this is very vague. What actually *is* chemical information, on your definition?
- "Electromagnetic information or waves that interact at large distances" -- why would this not be the same as "encrypted information"? It's not clear to me that these categories are labelling distinct ideas.
- "Networks storing information." Again, presumably encrypted information can be stored in a network. Ditto for "Spatial-Temporal information".
- "Synergy is the process that uses information to increase free energy" -- So synergy itself is not a type of information, which means it shouldn't really be in this list.
- "In information theory and statistics, negentropy is used as a measure of distance to normality." -- What does "normality" mean here?
- "Work, Entropy Production, and Thermodynamics of Information under Protocol Constraint" -- the final word in this title should be "constraints" plural.
- "Smith, J. (2000) describes Biological information as a product of Natural selection" I presume you mean John Maynard Smith. His full surname is Maynard Smith, not just Smith.

Complexity and Information

"Yet not all increase in complexity leads to an increase in useful information. Longer constitutions with more articles do not achieve better socioeconomic results of their countries than shorter ones." -- It is not at all clear what the relationship is between sociopolitical questions like this and the thermodynamics of information, chemistry and biology. I would stick to discussions of the natural sciences -- it's complicated enough without bringing the human sciences into the picture.

Structural Information

- "The information required to build it and the information that it transmits to the processes occurring inside the structure." -- This isn't a full sentence, so I'm not sure exactly what you're saying.
- "The more complex the structure the more information it carries and the more information is required to build it." -- But you just said the opposite about the genome, right? Isn't this inconsistent, or am I missing something?
- "Structural information is also related to the border conditions of a process. A chemical reaction is modulated by an

enzyme that constraints the reaction, and thus imposes border conditions on it." -- I don't really know what you mean here. Some more explanation and perhaps an example would help.

Knowledge and Information

I would delete this section entirely. I don't think it's adding anything to the central theme.

Negentropy and Information

- "Complex systems have many components, each of which with different thermodynamic processes. Thus, properties such as Entropy (S) may not be uniform. S by definition can not be negative as the third law of thermodynamics states that at T = 0o K, S = 0. Thus negentropy, although having properties that are opposite to that of S are of a different nature and can be better called information I that refers to information that increases Free Energy F and produces Synergy." -- This is a very difficult paragraph to understand, and as mentioned above seems to identify Shannon's definition of entropy with the thermodynamic definition, which is an unorthodox interpretation and should be explained.
- "In physics, the simile of Maxwell’s demon seems to be more appropriate in dealing with the relationship between energy and information (Maruyama et al 2009)." -- Could you explain the Maxwell's Demon thought experiment? It's been mentioned a few times already without actually being described.

Conclusions

"Complexity and its different forms is a first choice to estimate information." -- Nothing you've said so far explains why this might be so. I'm really not following. How exactly can you use complexity to estimate information?

Infodynamics and Thermodynamics

- We really need Maxwell's Demon to be fully spelled out here.
- "Jaffe 20123" presumably this should be 2023.
- "The problem here is that order and complexity are related, and these measures depend on the level of complexity addressed." -- I still don't really know what order or complexity are, and you haven't told us what levels of complexity are either.

Examples

Engine (heat)

"The concept of information is not needed to explain the thermodynamic behavior of this system" -- Well, some would say the physical structure of the engine provides constraints that ensures the free energy is converted into work, and that this constraint-producing-structure is itself a form of information. You yourself say there is something called "Structural information", so it would be good to address this point here. See e.g. Haig 2014: https://link.springer.com/article/10.1007/s10539-014-9432-4, section "Darwin's demon". (NB and it looks like you say something similar yourself after the very next example.)

Cannon (powder and ball)

This is a good example, and is similar to the example from Haig I referenced above. I think Kauffman has said something similar in *Investigations* (2000).

Photosynthesis

- "The process." This isn't a sentence.
- "It produces Free Energy F due to its highly complex structural information content Φ." So far you have described these things and given formal terms that correspond to them. Is there any hope of actually *measuring* F and Φ for these examples? That's what would be really exciting.

Life and Sex

- "Specifically, sex achieves increases in genetic information that increases Φ of future generations (Jaffe 2018)." I don't really have a good handle on what exactly Φ is, so there's no way of figuring out whether this statement is correct or not.
- "Life is a complex system that invented sex and cognition as a means to accelerate evolution to manage increments of Φ." The idea that cognition "accelerate[s] evolution" is a very strong claim and should be supported with an argument. It is an unorthodox thing to say.
- "useful information (ΔΦ) produces increments in free energy (ΔF >0). As ΔF helps access more information triggering an evolutionary process aiming at ever more complexity and more F and Φ is possible. This process is analogous to that described as autopoiesis by Maturana and Varela (1991)." -- This is too broad for us to be able to evaluate. It would really help to give a worked example of e.g. the cannonball or the engine, with actual numbers for F and Φ. Then we could see how they interact, and get an intuitive grasp of how they might apply in these more complex cases.

Conclusion

- "Our conclusion based on the sample of examples given above and on 15 more detailed empirical studies presented in (Jaffe 2023)." -- Do you give examples with numbers in that article? If so, you should mention it here, because readers will want to see them.
- "Information and energy are two different physical realities" -- This is a strange thing to say. I can't really figure out what you mean.

Multidimensional Systems and Emergence

Your main proposition seems to be that "increases in free energy are always associated with increases in information" but I don't see an argument for this, or even a worked example showing it is true for a single case.

Energy, Information and Emergence

- "However, there is no receipt to discover useful information." -- I guess you mean "recipe".

- "The different types of energy (Ei) and of information (Ii) in multidimensional systems have to be identified in order to understand this dynamic relationship." I agree.
- "But to advance we need more efforts in bridging the communication gap between the different disciplines involved in studying these phenomena so as to accelerate the growth of knowledge we have about these concepts and make them more useful for eventual practical and theoretical implementations." I agree with this too.
- "Increases in entropy ($\Delta S>0$) decreases free energy ($\Delta F <0$) and might affect the amount of useful information available in the system ($\Delta \Phi<0$)." This sentence is repeated.