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Entropy and Negativity: The Ecological Implications of Dialectics

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Abstract

Entropy, often defined negatively as disorder or randomness within a system, is vital for organisation while also posing a threat to cyclical reproduction. Entropy is not equivalent to disorganisation, but rather a source of creativity at the local level, even if the tendency towards entropy persists globally. In this article, we build upon Bernard Stiegler's understanding of entropy, and argue that the interplay of entropy and anti-entropy can be comprehended through Hegel's notion of negativity, and draw upon the organisational approach to biological systems, which introduces anti-entropy as akin to organisation. Thus, we address Stiegler's lopsided criticisms of dialectical accounts and argue that the interplay between entropy and anti-entropy is inherently dialectical. We also employ the concept of habit to understand the dialectic of entropy and anti-entropy in the life of organisms, and the delicate balance between stability and variability that must be upheld for the thriving of both organisms and their environments.

Keywords: Negativity; Entropy; Dialectics; Organisation

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Introduction: Stiegler and Dialectics

> Should one claim that, unless they have studied the *Science of Logic*, these scientists don't know what they are doing? Doubtless, they know what they are doing but, philosophically speaking, they often do not know what they know and beyond a certain point this limitation cannot but have a regrettable influence on their work.[1]

Doing philosophy in an era of unprecedented environmental crisis requires an engagement with scientific theories and hypotheses that are relevant for the existential and political challenges that beset human societies. Amidst an overwhelming consensus that the rate of consumption of energy resources is directly linked with the (un)viability of the biosphere in terms of rising temperatures and further climate disasters to come, philosophy is forced to explore the theoretical and practical implications of thermodynamics not only as an abstract and speculative exercise but as an ethico-political imperative.[2] In a sense, the urgency of our current predicament demands a dialogue between philosophy and the natural sciences which counteracts the increased specialisation and fragmentation of both disciplines.

If we subscribe to the view that dialectics is not a static body of work but a dynamic and naturalistic method that must be updated in light of scientific findings, we must come to terms with the science of thermodynamics.[3] Following the dialectical ideal of distilling philosophical principles from science in a critical manner, we develop the links between the science of thermodynamics and dialectics, focusing on the notion of negativity. We do not argue that entropy and negativity are identical but that they may inform each other; we demonstrate that a dialectical understanding of entropy and anti-entropy is able to accommodate the productive dimension of the former, a view which is suggested by Eric D. Schneider and Dorion Sagan.[4] However, before we proceed to explore the conceptual and theoretical

1 Lucien Sève, "Dialectics of Emergence," in *Dialectics for the New Century*, ed. Bertell Ollman and Tony Smith (New York, NY: Palgrave Macmillan, 2008), 91, https://doi.org/10.1057/9780230583818.

2 Joel White, "Outline to an Architectonics of Thermodynamics: Life's Entropic Indeterminacy," in *Contingency and Plasticity in Everyday Technologies*, ed. Natasha Lushetich, Iain Campbell, and Dominic Smith (New York and London: Rowman & Littlefield, 2022), 184.

3 Hub Zwart, "Friedrich Engels and the Technoscientific Reproducibility of Life," *Science and Society : A Journal of Marxist Thought and Analysis* 84, no. 3 (2020): 369–400; Guido Seddone, *Hegel's Theory of Self-Conscious Life* (Leiden: Brill, 2022), https://doi.org/https://doi.org/10.1163/9789004527638.

4 We do not discuss the topic of the heat death of the universe, as it is not important for our discussion. For an exploration of this question in relation to dialectics, see Foster and Burkett "Classical Marxism and the Second Law of Thermodynamics: Marx/Engels, the Heat Death of the Universe Hypothesis, and the Origins of Ecological Economics," *Organization & Environment* 21, no. 1 (January 17, 2008): 3–37, https://doi.org/10.1177/1086026607313580.

interweaving of entropy and negativity, we introduce Bernard Stiegler's appropriation of entropy, which is an account of thermodynamics couched in explicitly anti-dialectical terms.[5]

Stiegler's application of the concept of entropy to sociotechnical configurations is one of the most fruitful philosophical explorations of the implications of thermodynamics for living systems. Stiegler argues that "the *relation entropy/negentropy is really the question of life par excellence*,"[6] and his perspective of thermodynamics has informed an ecological critique of how the technical and the economic system have generated entropy at a global level, leading to environmental degradation which is now synonymous with the Anthropocene era. He introduces a technical and political *therapeia* of cultural transindividuation as a general organology of social, technical, and biological systems that produces anti-entropy or, in his words, "negentropic bifurcations."[7] Further, he applies terms such as the Anthropocene and the Entropocene interchangeably in contraposition with the term "Neganthropocene." While he sometimes speaks about negentropy, Stiegler prefers the more accurate term "anti-entropy" since entropy is a property of a system that is irreversible and thus the term negative entropy could signify a reversibility that is rejected within thermodynamics.[8]

Stiegler's appropriation of the concept of entropy draws heavily on the work of the economist Nicholas Georgescu-Roegen. The latter explores the implications of the Second Law of Thermodynamics for economics by emphasising how economic activity involves the transformation and utilisation of energy and matter from its surrounding environment, resulting in the production of waste and entropy.[9] His fundamental premise is that natural resources are finite, which indicates the unsustainability of economic models based on the idea of perpetual growth.[10] In this regard, Georgescu-Roegen can be seen as the founder of the field of ecological economics.

Strictly speaking, the Second Law predicts increase of entropy in isolated systems that are in thermodynamic equilibrium. But living organisms, social systems, and even the Earth (since it receives organized energy from the sun) are not isolated. These open systems are, however, subsystems of a larger and isolated system. Open systems retain their functioning and cohesion far from equilibrium by

5 Pieter Lemmens, "Love and Realism," *Foundations of Science* 22, no. 2 (2017): 307, https://doi.org/10.1007/s10699-015-9471-6.

6 Bernard Stiegler, "The Neganthropocene," trans. Daniel Ross (London, UK: Open Humanities Press, 2018), 39.

7 Stiegler, "The Neganthropocene," 51.

8 Stiegler, "The Neganthropocene," fn305, 416.

9 Nicholas Georgescu-Roegen, "The Entropy Law and the Economic Process in Retrospect," *Eastern Economic Journal* 12, no. 1 (1986): 3–25.

10 Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process* (Cambridge, MA: Harvard University Press, 1971).

exporting entropy through transformations of energy and matter to the larger system which they belong to. As such, they reflect the environment they are coupled with.[11] (More on this in part 2.)

Building on Georgescu-Roegen's theory, Stiegler calls for a re-invention and re-configuration of technical systems and their social organisation to resist and defer at a local level the inevitable increase of entropy perpetuated by economic activity. Ours, according to Stiegler, is *The Age of Disruption*, an age where digital technologies have produced entropy not only in the concrete sense of environmental degradation but also on the psychosocial level impairing the faculties of the *spirit*, such as reason, attention and dreaming.[12] Stiegler's understanding of entropy and anti-entropy is not informed by dialectics but in opposition to it. He admits that Hegel was one of the first philosophers that posited the question of exteriorisation as a moment of Spirit, a process that is conceptually aligned to Stiegler's theory of technics as an *exosomatisation of noesis*.[13] In this view, our interiority is constituted in the process of its exteriorisation. Yet, Stiegler charges both Marxist and Hegelian versions of dialectics for being "metaphysical," of ignoring that the forces at play are inherently pharmacological (that is simultaneously curative and toxic), and indeed tragic.[14]

Stiegler does not explain in depth why the dialectical perspective is incompatible with a tragic view of life.[15] Instead, he accused Hegel of believing that the discrete elements of Spirit can be united under the "*grand synthesis of absolute knowledge*," a belief that Stiegler attributes to the fact that Hegel "was *completely unaware* of the *indissoluble* play of entropy and negentropy."[16] Although this fits his general disapproval to theories of technics that are dialectical, proposing instead the relationship between living organisms and technics as organological, Stiegler seems to misrepresent dialectical movement as leading to "a grand synthesis," ignoring the dialectical interplay between complexity and organisation as anti-entropic. In other words, Stiegler disapproves of a dialectical perspective because it allegedly

11 Georgescu-Roegen's view, often conceptualised and criticised as the "Entropy pessimist thesis" implies that economic activity inevitably increases the entropy of the planet. But his argument seems to stand up to scrutiny especially given that natural resources (especially fossil fuels) during the Anthropocene era are used in a faster rate than the rate that was required for them to be available.

12 Stiegler, *The Age of Disruption: Technology and Madness in Computational Capitalism*, trans. Daniel Ross, Reprinted (Cambridge, UK: Polity, 2019).

13 Stiegler, *The Age of Disruption*.

14 Elsewhere, Stiegler calls for a serious engagement with Hegelian dialectic and dialectical materialism - a project that for him entails a critique of dialectic and not its repetition. See Bernard Stiegler, *States of Shock: Stupidity and Knowledge in the Twenty-First Century*, trans. Daniel Ross (Cambridge, UK: Polity, 2015).

15 Stiegler, *The Age of Disruption*.

16 Stiegler, *The Age of Disruption*, 240, emphasis original.

assumes a state of equilibrium.[17]

A central objective of this article is to show that a Hegelian perspective on entropy is diametrically opposed to the version that Stiegler argues against. We aim to reveal how entropy and negativity might mutually shed light on each other, not to reduce one to the other. Further, we seek to show how different instances of negativity operate in nature, how it is both between organisms and within them, and how the lack of a clear distinction between inside and outside is another instance of negativity. We proceed in stages: In part 1, negativity as understood by Hegel is discussed and compared to the so-called organisational view. Part 2 elaborates on the topic of negativity in Hegel. Then, in part 3, we discuss entropy as understood by Schneider and Sagan in light of the previous parts. Next, we get more concrete about the notion of organisation, which is proposed here, before taking the discussion back to Stiegler by discussing the concept of habit in the conclusion. We do not pretend to be conclusive on any of the topics discussed; instead, we seek to develop some core similarities that should be developed further.

Part 1: Dialectics and Negativity

Dialectics is an inherently contradictory method because it has both a tendency towards systematisation and dissolution. It is simultaneously integrative and destructive; it strives to show how things are integrated, while revealing the fragility of any integrated totality.[18] The concurrent tendencies of organisation and dissolution are also reflected in the objects that dialectics studies—displayed *par excellence* by living organisms. But the tendency towards dissolution is not merely the opposite of the tendency towards integration. Instead, they are interdependent. You cannot build anything without destruction, while destruction needs positive material to work on.[19] We aim to show how this fundamental dialectical principle operates within the metabolic (or thermodynamic) relation between an organism and its environment, to shed light on the advantages of adopting a dialectical understanding of this interplay.

Some of the biologists that acknowledged the importance of the metabolic relation between the organism

17 One can also guess that there was a historical and political aspect in Stiegler's disapproval of Hegel's dialectics. In the *Neganthropocene* we read: 'I have argued for twelve years that capitalism is destroying the spirit. It is not just that the word spirit was used by thinkers who then inspired totalitarian practices – Hegel, whose dialectic became the dictatorship of the proletariat historically concretized as the Soviet Gulag' Stiegler, "The Neganthropocene," 68.

18 Zwart, "Friedrich Engels and the Technoscientific Reproducibility of Life."

19 Catherine Malabou, *The Future of Hegel: Plasticity, Temporality and Dialectic*, *The Future of Hegel: Plasticity, Temporality and Dialectic* (London and New York: Routledge, 2005), https://doi.org/10.4324/9780203489338.

and the environment employed an explicitly dialectical framework, as seen in the works of Richard Lewontin and Richard Levins.[20] Arguably, this view is also implicit in the organisational perspective on living systems,[21] discussed below. The common denominator for the notion that the organism is *both cause and consequence of itself* is Immanuel Kant's theory of teleological causality.[22] Hegel offers a crucial development of this theory, which is *realistic* because it does not regard this form of causality as merely regulative, but as a constitutive principle of the nature of living organisations.[23]

In Hegel's view, teleology is not just something we apply to understand living organisms; it is also constitutive for how we come to understand and orient in the world since we are also natural beings. Hence, he does not merely say that we must understand nature metabolically but that understanding itself is shaped by our metabolic relation, through practice—that mind and matter are shaped through each other.[24] Accordingly, teleology is more than heuristic; it is a fundamental prerequisite of knowledge.[25] We are not outside the circularity that we aim to disclose; we *become-together* with this process. But never in a simple or linear manner.

Based on this, it should not be controversial to align entropy and dialectics through the notion of negativity that animates the dialectical movement. This comparison also sheds light on a fundamental similarity between Hegel's philosophy and the organisational approach, which may challenge Stiegler's dismissal of dialectics. But we will get to this topic in due course.

20 This could also be cast as an emphasis on metabolism and reproduction of organisation, against the opposing emphasis on replication and hereditary reproduction. While modern biology has largely focused on the replication of DNA templates, it has forgotten about the ongoing reproduction of the organism that enables replication in the first place. The metabolic relation is primary to replication Eric D. Schneider and Dorion Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life* (Chicago, IL: University of Chicago Press, 2005).

21 Andrea Gambarotto, "Teleology and Mechanism: A Dialectical Approach," *Synthese* 201, no. 5 (2023): 155, https://doi.org/10.1007/s11229-023-04137-y.

22 Immanuel Kant, *Critique of Judgement* (New York, NY: Macmillan, 1892).

23 Georg Wilhelm Friedrich Hegel, *The Science of Logic*, ed. George Di Giovanni (Cambridge, UK: Cambridge University Press, 2010).

24 But this does not mean that cognitive autonomy can be reduced to metabolic autonomy. Even if teleology and the ongoing metabolic relation that organisms have to their environments is constitutive of who they are, new levels emerge which are also constitutive of who they are, and we cannot understand their identity without understanding how multiple integrative levels interact, again, constitutively. Xabier E. Barandiaran, "Autonomy and Enactivism: Towards a Theory of Sensorimotor Autonomous Agency," *Topoi* 36, no. 3 (2017), https://doi.org/10.1007/s11245-016-9365-4.

25 Alison Stone, "Hegel, Naturalism and the Philosophy of Nature," *Hegel Bulletin* 34, no. 1 (2013): 59–78, https://doi.org/10.1017/hgl.2013.2.

In the organisational perspective—which emphasises the cyclical reproduction of the whole organisation of constraints that together enable the reproduction of living systems (called *closure of constraints*)—anti-entropy is the local increase of organisation at the expense of disorganisation in adjacent systems.[26] It is a process of complexification or differentiation which makes use of the global increase in entropy to produce local organisation. This echoes Hegel's concept of negativity as a process of differentiation, of moving from what is generic or abstract towards what it specific or concrete. The movement is displayed in the stages he depicts in his *Philosophy of Nature*, wherein the organic level emerges from its dialectical interaction with the chemical and physical level.[27] These other levels are not completely distinct, nor are they left behind once and for all. Instead, they are sublated, which involves the emergence of a new, living totality, which constrains the functioning of the physical and chemical parts and thereby exhibits self-determination.[28]

As we develop more below, anti-entropy, which is tied to biological organisation, means that one system organises at the expense of another. This is like the Hegelian notion that organisms must extract energy (i.e., negative entropy) from other organisms, which is a process of *assimilation*. A living organism must be energetically open to remain organisationally closed. It cannot be itself except through this relationship. This, Hegel argues, is the *ultimate contradiction*, that identity is only possible by being open to otherness:

> What Hegel is trying to show is that any kind of independence *depends* on otherness, even at this primitive stage where independence means (1) dependence on the other through the destructive assimilation of the other, and (2) the transgression of the very boundary of the self that is paradoxically perpetuated by this very transgression.[29]

A living organism is characterised by the capacity to sustain this contradiction, to maintain itself through the other. It is not only subject to lack but also able to feel and to act upon it, which is to say

26 Maël Montévil and Matteo Mossio, "Biological Organisation as Closure of Constraints," *Journal of Theoretical Biology* 372 (May 7, 2015): 179–91, https://doi.org/10.1016/j.jtbi.2015.02.029.

27 Georg Wilhelm Friedrich Hegel, *Philosophy of Nature: Part Two of the Encyclopaedia of the Philosophical Sciences*, trans. A. V. Miller, With Foreword by J. N. Findlay (Oxford, UK: Oxford University Press, 2004).

28 Luca Corti, "The 'Is' and the 'Ought' of the Animal Organism: Hegel's Account of Biological Normativity," *History and Philosophy of the Life Sciences* 44, no. 2 (2022): 1–22, https://doi.org/10.1007/s40656-022-00498-8.

29 Søren Rosendal, "The Logic of the 'Swamp World': Hegel with Kafka on the Contradiction of Freedom," in *Kafka and the Universal*, ed. Arthur Cools and Vivian Liska (Berlin and Boston: De Gruyter, 2016), 72–73, https://doi.org/doi:10.1515/9783110458114-004.

that the negativity of lack is constitutive of its activity and thereby shapes what it is.[30] Hence, it is both autonomous and dependent on the other. Here, negativity is both the other organism, and the process by which an organism maintains itself through this other. But negativity is not eradicated, as it persists as the process of negating concrete instances of negativity. In other words, positively given organisms are but a fragment of the process of negativity.

Part 2: Lack and Entropy

> The key to understanding the nature of entropy is in the word "lack," because entropy represents something that is rarely encountered in physics – an apophasis, or something that does not exist […]. The reader may wonder how it is possible to quantify something that does not exist, but it is done all the time in reference to something that does exist. For example, "The glass is half empty." quantifies how much fluid is missing in relation to the full capacity of the glass. There is a tendency for many to regard entropy as a positivist attribute, like the other variables of physics, and this misattribution is the source of much confusion about the actual nature of entropy.[31]

Entropy and lack are closely related. But how does that help us understand Hegelian negativity? The notion of entropy overlaps with the view that negativity enables something else to occur, i.e., that the lack in nature makes it plastic, opens a space for subjective intervention. This is encapsulated by Hegel's notion of the *impotence of nature*, of nature as weak in the sense that it cannot display its own logic in a faithful manner. Nature is, logically speaking, the sphere of necessity, but because it is also riddled with contingency, we cannot deduce its singular instances, only decipher its universal logic tentatively.[32] In other words, the concrete instances of nature cannot be derived from logical categories.

30 "The tension the organism experiences to overcome it condition, to pass the limit, to satisfy its restlessness pushes it to engage with the outside world, and makes it what it really is" Luca Illetterati, "Nature, Subjectivity and Freedom: Moving from Hegel's Philosophy of Nature," in *"I That Is We, We That Is I." Perspectives on Contemporary Hegel: Social Ontology, Recognition, Naturalism, and the Critique of Kantian Constructivism*, ed. Italo Testa (Leiden: Brill, 2016), 197, https://doi.org/https://doi.org/10.1163/9789004322967_012.

31 Robert E Ulanowicz, "Socio-Ecological Networks: A Lens That Focuses Beyond Physics," *Frontiers in Ecology and Evolution*, 2021, 3, https://www.frontiersin.org/articles/10.3389/fevo.2021.643122.

32 A consequence of this idea is that our logical apparatuses fail to deduce the concrete instantiations of nature, undermining the notion that Hegel proposes a theory of everything, and that absolute knowing is about knowing everything. When Hegel says 'absolute' what he means is something that has no outside, as we shall see below. Dialectical reason cannot deduce the individual shapes of nature, but it can explain *why* this is impossible. Insofar as we can define idealism as the notion that our categories are able to grasp their concepts completely, Hegel's theory is not idealist, as he insists that there is always a remainder, that nature is too weak to embody concepts in a faithful manner. Concepts are therefore only approximations – involved with and shaped by what they describe.

According to Hegel, the contingency of nature imposes limitations on science and philosophy. This undercuts the claim that his notion of absolute *knowing* is about the culmination of knowledge.[33]

Because nature is weak in this way, it cannot resist our attempts at changing it. It is not only external to us but external to its own conceptual structure, unable to control its own development.[34] This converges on the view that you cannot deduce the properties of the living from the properties of the inert, even if the former must comply with the latter.[35] Had nature been strong, we would be determined rigidly by natural laws, as nature would be a sphere of complete determination. Thus, our subjectivity would be an epiphenomenon.

Similarly, had entropy been strong, something like organisation could not emerge from it. The universal tendency towards disorganisation would encompass entropy fully—nothing else could emerge from this process. The weakness of entropy, by contrast, is displayed by its contradictory nature, by the notion that it enables anti-entropy to emerge from within.[36] Hence, entropy opens the space for something else. As Ulanowicz writes: "entropy cannot cause events in the same way that positivist forms and forces do. Rather, absence *affords opportunity* for positivist tendencies to act. It functions as a secular form of kenosis."[37]

Hegel argues that negativity is not a *thing* but a process of differentiation. It therefore has different vicissitudes. Hegel begins with the abstract definition of negativity as pure absence, the lack that Ulanowicz speaks of in the epigraph.[38] This conception of negativity places it outside what we can comprehend, and therefore misses its positive dimension. Negativity, in the abstract version, is Kant's *thing in itself*, outside possible experience, pure nothingness. But from this abstract beginning, Hegel finds that negativity is the motor of dialectics, and depicts dialectics as the process by which the abstract beginning is sublated and concretised.

If one conflates negativity and nothingness, one overlooks the positive dimension of negativity, the activity of negating concrete forms, and relating to these forms again. Hence, we need to understand

33 Malabou, *The Future of Hegel: Plasticity, Temporality and Dialectic*.

34 Luca Illetterati, "Nature's Externality: Hegel's Non-Naturalistic Naturalism," ed. Mladen Dolar, *Problemi* 58, no. 11–12 (2020): 51–72.

35 Giuseppe Longo and Maël Montévil, "From Physics to Biology by Extending Criticality and Symmetry Breakings: An Update," *Acta Europeana Systemica* 9 (2020), https://doi.org/10.14428/aes.v9i1.56043.

36 Marie Chollat-Namy, Giuseppe Longo, "Entropie, Neguentropie et Anti-entropie : le jeu des tensions pour penser le vivant," *ISTE OpenScience*, vol. 4 (2022), 10.21494/ISTE.OP.2023.0983

37 Ulanowicz, "Socio-Ecological Networks: A Lens That Focuses Beyond Physics," 4.

38 Hegel, *The Science of Logic*.

the concrete forms of *absolute negativity*, which has no outside because it is absolute. In other words, abstract nothingness cannot stably exist, and yet there is always a remainder of nothingness in the concrete forms of negativity, in the sense that there is something that is not yet actualised. It is the abstract possibility of breakdown inherent in each transient form. This is how the beginning reverberates in its products.

For our purposes, what is most important is the notion that there is no positively given ground. Each step forward is a further determination of the beginning. Negativity is therefore an activity that constantly returns to itself, through the process of actualisation that it enables. It is a principle of movement. Hegel writes that the negative:

> belongs to the content itself and is the *positive*, both as its *immanent* movement and determination and as the *totality* of these. Taken as a result, it is the *determinate* negative which emerges out of this movement and is likewise thereby a positive content.[39]

The fact that negativity is absolute and self-referential means that individuation has no outside, that the process of actualisation produces its potential retroactively. It makes use of the lack of a stable ground to produce this ground progressively. The abstract beginning is negated or sublated and thereby made concrete.[40] Hegel underscores that:

> The view that the void constitutes the ground of movement contains the more profound thought that the ground of becoming, of unrest and self-movement, lies in the negative in general, which, in this sense, is however to be taken as the true negativity of the infinite. – The void is the *ground of movement* only as the *negative* reference of the one to its *negative*, to the one, that is, to its own self posited, however, as determinate existent. [41]

The void, or lack, is only a ground *through* its products. Every determination is therefore a confirmation and a negation of this abstract ground which opens the space for intervention.

39 Georg Wilhelm Friedrich Hegel, *The Phenomenology of Spirit* (Cambridge, UK: Cambridge University Press, 2018), 37 emphases original.

40 As one of the anonymous reviewers pointed out, this is reminiscent of the notion of "default of origin" that we find in Stiegler's works. For lack of space, we cannot develop this further here, but the reader can consult Bernard Stiegler, *Technics and Time, 1: The Fault of Epimetheus*, trans. Richard Beardsworth and George Collins (Stanford, CA: Stanford University Press, 1998), 114.

41 Hegel, *The Science of Logic*, 135.

At the level of life, this opening is exploited when the organism resists determination from without—when it negates and sublates chemical and physical processes to enable its further existence. To be sure, this does not imply that physical or chemical processes are nullified, only that they operate differently within a living system. A living being is a subject because it self-determines, because it reproduces its own organisation cyclically.[42] The organism, as a self-referential whole, therefore instantiates what Hegel refers to as "true infinity," which is not the numerical infinity that extends towards some hidden goal but ever reaches it. Instead, infinity is about reflexive determination, self-related negativity. It is the infinity of the cycle that maintains organisation—that extends into its surroundings and integrates it into its own functioning. In a word, it is the infinity of life.

At this stage, negation manifests as the lack or deficiency that an organism feels, and which makes it necessary for it to assimilate its environment. We should understand this assimilation in a broad sense—not just about material processes but also with the affordances that the organism is able to detect. This contradiction is formative and is reminiscent of what Merleau-Ponty (influenced by Hegel's works) spoke of as *disequilibrium*. The organism constantly strives to eliminate this disequilibrium but cannot achieve this feat without undermining its own existence. The experienced disequilibrium initiates movement and is only overcome when the organism dies.

Due to this contradiction, organisms are never able to establish an *optimal grip* on their situation, never able to master their environment fully.[43] This lack is simultaneously the condition of possibility for meaningful interaction. It is what Hegel considered the problem of nature—how it can never be fully internalised by the organism, while also enabling its existence.[44] It points to the absolute contradiction—that the organism remains self-identical only through its constitutive relationship with the outside world, how identity is conserved through transformation. Arguably, this is also the view that we find in the notion of anti-entropy, to which we now turn.

42 Giuseppe Longo and Maël Montévil, *Perspectives on Organisms: Biological Time, Symmetries and Singularities* (Berlin and Heidelberg: Springer, 2014), https://doi.org/10.1007/978-3-642-35938-5.

43 Barbara Stiegler detects a similar idea in Nietzsche's writings which for her amounts to an early critique of adaptationism. See Barbara Stiegler, "1880: First Philosophical Critique of Adaptationism Nietzsche, Reader of Herbert Spencer," in *Naturalism and Social Philosophy: Contemporary Perspectives*, ed. Martin Hartmann and Arvi Särkelä, Essex Studies in Contemporary Critical Theory (Lanham: Rowman & Littlefield, 2023), 65–79. We thank one of the anonymous reviewers for making us aware of this work.

44 Wes Furlotte, *The Problem of Nature in Hegel's Final System* (Edinburgh: Edinburgh University Press, 2018), https://doi.org/10.3366/edinburgh/9781474435536.001.0001.

Part 3: Entropy and Anti-entropy

> [N]ot only does the organization of the new whole not derive from the old one, but the disorganization of the latter is a prerequisite for its reorganization on a new basis. Isn't it this essentially dialectical logic that assumes such spectacular forms in such non-linear phenomena as chaos, bifurcation and auto-organization?[45]

Schneider and Sagan introduce the notion that nature "abhors a gradient"—and therefore seeks to collapse them—to demystify what entropy is about.[46] Less a generic tendency towards disorder, they understand entropy more as a process that generates complex natural forms. This is also what Sève is getting at in the above quotation. New organisations may only arise against the background of disorganisation. When organisms act based on the feeling of lack, they *embody the second law*, as they strive to collapse the gradient that affects them. They extend outwards due to the feeling of lack, which is another expression of negativity.

This indicates the usefulness of comparing negativity to entropy. Just as anti-entropy is not the opposite of entropy, so positivity is not the opposite of negativity, but a manifestation of the process of negation of concrete forms. As such, negativity relates to and responds to itself through the other. The same goes for entropy, since the entropy that the organism faces in its environment is partly produced by itself. Although Schrödinger posited that living organisms "maintain their internal organization at the expense of larger increases in randomness outside their bodies,"[47] we could say that in creating an ecological niche they increase the organisation of their environment. However, in doing so they use energy leading to the generation of entropy.

Likewise, Schneider and Sagan emphasise the enabling role of entropy. We could say that it produces the impetus for action that is expressed as a feeling of lack at the level of life, but it also speaks to principles that are shared by all systems shaped through gradients, living or not. (Of course, we are not saying that inert entities experience entropy although they are affected by it.) The dialectical notion of entropy affords a scientifically informed process ontology of differentiation of levels, of individuation without a positively given ground—and explain anti-entropic behaviour as a kind of alienation or externalisation, where the organism gets its own message in return, but never in a manner that it may predict. This allows us to understand entropy as a process of differentiation (negation), of co-evolution.

45 Sève, "Dialectics of Emergence," 94.

46 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*.

47 Erwin Schrödinger, *What Is Life? The Physical Aspect of the Living Cell* (Cambridge, UK: Cambridge University Press, 1944), 17, https://doi.org/LK - https://worldcat.org/title/499840714.

In this view, anti-entropy is the concrete negation of entropy, disrupting and making use of it to its own ends.

Schneider and Sagan ask how organisms can survive and maintain the organisation given the tendency towards disorder prescribed by the second law: "organisms are organized to resist thermodynamic equilibrium."[48] Organisms produce entropy in the supra-individual systems they belong to in the degraded products that they transport to their surroundings.[49] This paradox is solved in a manner that we could call "dialectical":

> The basic answer to the paradox has to do with context and hierarchy. Material and energy are transferred from one hierarchical level to another. To understand the growth of natural complex systems such as life, we have to look at what they are part of—the energy and environment around them. In the case of ecosystems and the biosphere, increasing organization and evolution on Earth requires disorganization and degradation elsewhere. You don't get something from nothing.[50]

Life displays increased complexity over time, even if matter tends towards randomised distribution. It therefore seems to overcome entropy. But as Schneider and Sagan remark: "Not only is life not removed from the thermodynamic imperative of the second law, but it is also its most impressive and awe-inspiring manifestation."[51] Like negativity, then, the tendency towards destruction gives rise to determinate negations, while at the same time threatening all such positive phenomena. We thus get a sense of why the negative is equally positive. Negativity is a process that manifests itself in positively given phenomena, like the life cycle that maintains the organism.

The dialectical coincidence of opposites is evident at the level of life, where the organism is constituted by its continual dialogue with its environment. According to Schneider and Sagan, all open systems, i.e., systems that exchange matter and energy with their outside, are able to defy the second law by accelerating the "reaching of equilibrium in the areas *around* them."[52] By internal organisation, gradients around livings systems are eliminated. But such systems reproduce themselves cyclically not only by

48 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 16.

49 In other word, the quality of the energy changes, as it is made use of. It is no longer free energy, i.e., energy that can perform physical work (even if this does not mean that it cannot in principle become useful again). In accordance with the second law, the sheer quantity of energy does not change, only the quality.

50 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 15–16.

51 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 71.

52 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 71.

eliminating gradients but also by producing them—increasing the entropy of the larger system in which they are embedded. Waste is always the biproduct of reproductive cycles; systems export entropy from the inside to the outside to endure through time.[53]

Thus, we could understand the notion that the organism responds to something that it is partly responsible for producing, and thus to the products of its own activity—a response to gradients that it has modified itself.[54] As Ulanowicz writes: "Taken as a unit, the autocatalytic cycle is not simply reacting to its environment; it also actively creates its own domain of influence."[55] This indicates how thermodynamics can contribute to a more ecological science.[56]

Part 4: The Organisation of Chance

> Schrödinger sought new concepts to reconcile thermodynamic theory with biological fact. At first glance, he noted, living systems seem to flout the second law of thermodynamics. Energy and material in enclosed systems will become randomly distributed over time. Living systems, however, are the veritable opposite of such disorder. Living in an environment tending toward disorder, they increase their order. And order is not the best word. A better word for organisms is organization—organisms are organized to do something—to live, to reproduce, to keep on going as they are. Said otherwise, organisms are organized to resist thermodynamic equilibrium.[57]

Entropy is the tendency towards disorganisation, while anti-entropy is a tendency towards organisation. As Schwartzman puts it: "On a cosmological scale, the increase in entropy in the universe is inevitable,

53 White, "Outline to an Architectonics of Thermodynamics: Life's Entropic Indeterminacy."

54 The touches on the concept of niche construction, which is also an example of how the organism externalises itself by being impelled outward (see Odling-Smee, Laland, and Feldman 2003; Sultan 2015; Uller and Helanterä 2019). We cannot expand on this here, but it operates in the background.

55 Robert E. Ulanowicz, "Beyond the Material and the Mechanical: Occam's Razor Is a Double-Edged Blade," *Zygon®* 30, no. 2 (1995): 256, https://doi.org/10.1111/j.1467-9744.1995.tb00068.x.

56 The notion of self-organisation is therefore misleading. Nothing *self*-organises apart from its environment. See Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 85. Rather, the self, the organism, is the product of a process of gradient-organisation. The environment is therefore internally related to the constitution and functioning of a living organism. This critique extends to the notion of autopoiesis, but this topic lies outside the scope of this article but confer Di Paolo "The Enactive Conception of Life," in *The Oxford Handbook of 4E Cognition*, ed. Albert Newen, Loen De Bruin, and Shaun Gallagher (Oxford, UK, 2018), 71–94.

57 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 16.

as expressed in the second law, but this very increase is the necessary requirement for the emergence and maintenance of self-organised systems. The debt of self-organising systems to "chaos" is the environmental increase in entropy."[58] But the closure of living systems is never complete. Had it been, the organism would no longer be precarious and therefore also lack dynamicity. The precarious status of the organism impels its continuous anti-entropic activity. Entropy is therefore both a source of disorganisation and organisation. It allows us to grasp what Merleau-Ponty spoke of as the simultaneous relative equilibrium and disequilibrium.[59] The disequilibrium is the lack that spurs the organism to act and what provides its environment with normative value. But this is perceptible only at the level of life, which is where anti-entropic activity occurs. We see, then, how the concretisation of entropy in the specific sphere of living systems sheds light on the nature of entropy, which is only described in generic terms within physics.

We should, however, not confuse low entropy with organisation. As Mäel Montévil explains: "Everything that contributes to the low entropy of biological situations is not relevant for their organizations. For example, a cancerous tumour increases morphological complexity but decreases organization."[60] To get at the difference between low entropy and anti-entropy, the notion of *closure of constraints* is crucial.[61] It denotes the cyclical determination of a biological organisation, where the whole and the part are reciprocally determined. The different constraints, which are local boundary conditions on processes, become organised in a manner where they regenerate the whole system through their interdependence. This is the definition of closure which is specific to living systems. Organisation or anti-entropy is the specific canalisation of entropy, making it useful for the organism while also producing entropy.

From the differentiated structure of constraints emerges a dynamic totality, the organism, which integrates all the constrains into its functioning. This cyclical determination is a form of *self-determination*, as the organism is able to maintain itself through its own activity. It achieves organisational autonomy, while remaining energetically and materially dependent on its surroundings. The simultaneous openness and closure enable it to maintain its identity amid constant change—the absolute contradiction we spoke of above.

58 David Schwartzman, "The Limits to Entropy: Continuing Misuse of Thermodynamics in Environmental and Marxist Theory," *Science and Society* 72, no. 1 (2008): 51–52, https://doi.org/10.1521/siso.2007.72.1.43.

59 Rietveld, Denys, and Van Westen, "Ecological-Enactive Cognition as Engaging with a Field of Relevant Affordances: The Skilled Intentionality Framework (SIF)."

60 Maël Montévil, "Entropies and the Anthropocene Crisis," *AI and Society*, 2021, no pagination, https://doi.org/10.1007/s00146-021-01221-0.

61 Montévil and Mossio, "Biological Organisation as Closure of Constraints."

Beside the organisational closure specific to organisms, we should also highlight its historicity—how its interaction with the environment is integrated into its functioning. Montévil summarises:

> In a nutshell, we propose to consider that an element relevant for anti-entropy satisfies three criteria. i) It contributes to organization *sensu* closure of constraints; informally, it has a systemic role in an organism's persistence. ii) It is the specific result of history. iii) The specific properties in (ii) are the condition for the systemic role in (i).[62]

From this, Montévil draws the conclusion that anti-entropy must be gauged in relation to organisation, and that one biological organisation might undermine another, by reducing its anti-entropy.

Organisation is a synonym for life.[63] Hegel defines life as a chemical process which is able to sustain itself over time, becoming a metabolism.[64] As we have seen, it must move outwards to achieve this. As such, life is characterised by the cyclical organisation of chemical processes, whereby the whole system integrates and self-reproduces thorough the other. Compare this to a thermodynamic definition: "Living systems are metastable processes that maintain their identity."[65] A process able to maintain its identity is a process that organises its material components into an integrated totality, where each part depends on the whole system and vice versa.

The term *negative entropy* obfuscates how we should understand negativity in relation to entropy. The term anti-entropy is more useful, as it encompasses the dialectic between entropy production and the production of organisation. Entropy, in this view, does not only undermine any stable organisation but enables it in the first place. It is the lack of determination that makes something like a living organisation possible. Bailly and Longo point to Schrödinger's definition:

> His idea is that what counts for a living organism is its organization and that the problem which poses itself is not only its establishment ("the formation of order based on disorder"), but also its maintenance ("order based on order"). He emphasizes the importance, still unclear today, of the acquisition of organization as *negative entropy*, including by means of food. This acquisition will participate to the ongoing tension between the increase of entropy, specific to any irreversible thermodynamic process and generating disorder, and the maintenance of order.[66]

62 Montévil, "Entropies and the Anthropocene Crisis," no pagination.

63 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*.

64 Zwart, "Friedrich Engels and the Technoscientific Reproducibility of Life."

65 Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*, 86.

66 Francis Bailly and Giuseppe Longo, "Biological Organisation and Anti-Entropy," *Journal of Biological Systems* 17, no. 01 (March 1, 2009): 65, https://doi.org/10.1142/S0218339009002715.

Here, we see the contradiction or disequilibrium inherent in the relation between a living system and its surroundings. We also get at the notion that the canalisation of entropy also generates entropy which can be used at a later stage. At a global level there is always an increase in entropy. Living organisation counteract this tendency locally but cannot stop the global trend towards increased entropy. When a living system reproduces its organisation, it also produces entropy and disorganisation.[67]

Why is this important? For starters, it shows that anti-entropy is not merely the inverse of entropy but itself contributes to its production. Local anti-entropy makes use of available energy (exergy) but also releases entropy into the surroundings.[68] The exergy is therefore dependent on the historical couplings between the organism and its environment.[69] This circumstance hints at why self-determination includes the environment in which the organism is situated. Importantly, the production of entropy is therefore a source of variability, and thus potentially useful for the organism in situations that require it to adapt. It is the imperfect reiteration of the reproduction of the whole organisation that produces this entropy:

> biological reproduction, as morphogenesis, is *intrinsically associated to variability* and, thus, *it produces entropy also by lack of (perfect) symmetries*. By this, it induces *its proper irreversibility*, beyond (and in addition to) thermodynamic irreversibility.[70]

In physical systems, *symmetries* are invariant structures that only change rarely, that is, at specific critical thresholds. An example is the phase change when water goes from a liquid to a frozen or gaseous state. It has a clear limit at which the change occurs, and it happens in a predictable manner. Biological systems, on the other hand, are characterised by inherent instability and historicity. They undergo symmetry breaks continuously to stay alive. Thus, the situation is reversed compared to physics. Variance comes before invariance, and what is invariant is a product of history. This formalises Hegel's notion that biological systems only conserve their identity through constant change. They embody

67 Longo and Montévil, *Perspectives on Organisms.* Strictly speaking, the organisation of living system does not stem from negative entropy but from available energy, *exergy*, the quantity of usable energy that organisms can put to work. But the amount of exergy available is not given. Instead, it is the product of the interaction between the organism and environment. See Schneider and Sagan, *Into the Cool: Energy Flow, Thermodynamics, and Life*.

68 Montévil, "Entropies and the Anthropocene Crisis."

69 "Couplings are far more proteiform in biology than in the standard framework of thermodynamic. In artifacts and industrial processes, let us recall that the thermodynamic couplings correspond to the processes' purpose to generate usable work. In biology, couplings' plasticity corresponds to the variability of biological functions that is intrinsic to the historical changes of biological objects." Montévil, "Entropies and the Anthropocene Crisis", no pagination.

70 Longo and Montévil, *Perspectives on Organisms: Biological Time, Symmetries and Singularities*, 218.

negativity through their ability to sustain this contradiction. Thus, we see how the notion of anti-entropy is inherently dialectical.

Part 5: The Dialectics of Habits

Entropy is contradictory since it spurs the process of complexification forward, while at the same time undermining this process. Similarly, negativity is initially generic but develops into increasingly complex determinate negations. Should we not say that anti-entropy is to entropy what determinate negations is to negativity, that we speak about something abstract, a lack, which is instantiated in positive shapes but never stabilised because it is not a thing, but a process? In this view, we get a clearer sense of the dual nature of entropy; we also arrive at a notion of interaction as a concretisation of entropy.

We saw that negation of the abstract beginning produces determinate negations, but that these never sublate the abstract negativity. Another way to say this is to underscore how anti-entropy or organisation does not cancel entropy but canalises it, and thereby produces its own free energy or negativity. The reason we can call this entropy production "negativity" is because it is not positively given as a thing. It is only found in the individuation of living beings, as their inherent lack. One evident overlap between negativity and anti-entropy, then, is that neither is about cancellation but about canalisation. We could say that anti-entropy is entropy in the form of its other—itself in a fragmented form, in concrete identities that cannot be predicted from the law of entropy itself.

In this sense, when we view negativity and entropy as ongoing process of negation of determinate forms of organisation, the mutual benefit of comparison is evident. We get a clearer sense of the processual nature of entropy, and its dialectics with anti-entropy, and we can make negativity more scientifically intelligible. In a way, we get a sense of how we can understand Hegel's concepts more fully by updating them in light of scientific studies. This is related to the notion that logic cannot deduce the concrete instances of nature, and therefore needs to rely on natural science to disclose these instances. In the case of entropy, Hegel was on to something that was not yet discovered scientifically. He saw that development and evolution works through simultaneous synthesis and separation, that any complex system must be stable *and* fragile to develop. Hence, it is not enough to say that entropy is lack. Like negativity, entropy is lack but also the ongoing response to this lack, the negation of this lack in the form of anti-entropy.

Discussing the role of negativity in the interplay of entropy and anti-entropy which influences the behaviour and development of organisms, leads us to Hegel's concept of habit (*die Gewohnheit*) in understanding how living organisms reduce their own entropy yet increase the entropy of the wider system to which they belong. Habits, as behavioural predispositions towards the repetition of an action, are not easily classifiable as entropic or anti-entropic properties of the mind.[71] Apart from the normative conception of habits as "good" or "bad," the concept has an intrinsic relevance to questions about energy-efficient ways of dealing with the world. From one point of view, habits are anti-entropic in maximising the work that can be done with available cognitive resources, preventing the increase of entropy required by learning to execute a novel action. On the other hand, habitual behaviour is prone to error; prevents the exploration of more energy-efficient habits and can impede an increase in complexity which as we have seen is the fundamental process of how organisms resist entropy. Habits provide a mechanism to produce order that resists disorder, yet they might cause disorder indirectly through the generalised decrease of complexity. When habits are no longer aligned with the goals and the continuity of the living system, more energy might be required to transform or replace existing ones. This is particularly true when a habit become an addiction.

Hegel discusses the difficult and often-misunderstood nature of habit when he writes: "Habit is often spoken of disparagingly and taken to be a lifeless, contingent and particular thing." Yet, for him "habit is the most essential feature of the existence of all mental life in the individual subject."[72] The importance of habit lies in the fact that it mediates the contradictory processes of self-determination and world-determination.[73] Through habit the soul acquires its skills, abilities and predispositions which creates an inextricable connection between habit formation and ethical life.[74] For Hegel, habit has an all-encompassing character: "The form of habit includes all kinds and stages of spiritual activity. […] Similarly seeing, and so on, is the concrete habit which immediately unites in one simple act the many determinations of sensation, consciousness, intuition, intellect, etc."[75] Being a "mechanism of self-feeling" and a "second nature posited by soul,"[76] habit allows the individual to reach a level of self-determination which Hegel associates with freedom. Yet, habit can also enslave the individual. Hegel's

71 Kevin Maréchal, "An Evolutionary Perspective on the Economics of Energy Consumption: The Crucial Role of Habits," *Journal of Economic Issues* 43, no. 1 (March 1, 2009): 69–88, https://doi.org/10.2753/JEI0021-3624430104.

72 Georg Wilhelm Friedrich Hegel, *Philosophy of Mind*, trans. A.V. Miller and W. Wallace (New York, NY: Oxford University Press, 2007), 133.

73 Xabier E. Barandiaran and Ezequiel A. Di Paolo, "A Genealogical Map of the Concept of Habit," *Frontiers in Human Neuroscience*, 2014, 6, https://doi.org/10.3389/fnhum.2014.00522.

74 Elisa Magrì, "The Place of Habit in Hegel's Psychology," in *Hegel's Philosophical Psychology* (London and New York: Routledge, 2016).

75 Hegel, *Philosophy of Mind*, 132.

76 Hegel, *Philosophy of Mind*.

theorisation of habit is fundamentally ambiguous: On the one hand, habit is about deadening and ritualisation; on the other, it is the precondition for any exercise of freedom, the historical basis upon which creative activities may appear.

This perspective reminds us of Stiegler's concept of the *pharmakon* which, following Plato's suspicion towards writing in his *Phaedrus* and Derrida's uptake of this idea, allows him to conceptualise technical artefacts as both curative and toxic.[77] Habits, being inherently pharmacological in their simultaneously creative and entropic properties, constitute technologies of freedom which organisms use to transform themselves and their environments. However, as all technologies, habits can regress to automatisms leading to a decrease rather than an increase in functionality. While Stiegler understood the ambiguity of these phenomena, he ascribed to them a non-dialectical promise of *composition*, failing to follow through his own understanding of the dynamics between entropy and anti-entropy. The contradictory processes of habit formation provide a promising avenue for exploring the relevance of the Second Law and dialectics in how organisms shape themselves and their world.

77 Plato, *Phaedrus*, trans. Harvey Yunis (Cambridge, UK: Cambridge University Press, 2011); Jacques Derrida, *Dissemination*, trans. Barbara Johnson (Chicago, IL: University of Chicago Press, 2017).

Bibliography

Bailly, Francis, and Giuseppe Longo. "Biological Organisation and Anti-Entropy." *Journal of Biological Systems* 17, no. 01 (March 1, 2009): 63–96. https://doi.org/10.1142/S0218339009002715.

Barandiaran, Xabier E. "Autonomy and Enactivism: Towards a Theory of Sensorimotor Autonomous Agency." *Topoi* 36, no. 3 (2017). https://doi.org/10.1007/s11245-016-9365-4.

Barandiaran, Xabier E., and Ezequiel A. Di Paolo. "A Genealogical Map of the Concept of Habit." *Frontiers in Human Neuroscience*, 2014. https://doi.org/10.3389/fnhum.2014.00522.

Chollat-Namy, Marie, and Giuseppe Longo, "Entropie, Neguentropie et Anti-entropie : le jeu des tensions pour penser le vivant" *ISTE OpenScience*, vol. 4 (2022) 10.21494/ISTE.OP.2023.0983

Corti, Luca. "The 'Is' and the 'Ought' of the Animal Organism: Hegel's Account of Biological Normativity." *History and Philosophy of the Life Sciences* 44, no. 2 (2022): 1–22. https://doi.org/10.1007/s40656-022-00498-8.

Derrida, Jacques. *Dissemination*. Translated by Barbara Johnson. Chicago, IL: University of Chicago Press, 2017.

Foster, John Bellamy and Paul Burkett. "Classical Marxism and the Second Law of Thermodynamics: Marx/Engels, the Heat Death of the Universe Hypothesis, and the Origins of Ecological Economics." *Organization & Environment* 21, no. 1 (January 17, 2008): 3–37. https://doi.org/10.1177/1086026607313580.

Furlotte, Wes. *The Problem of Nature in Hegel's Final System*. Edinburgh: Edinburgh University Press, 2018. https://doi.org/10.3366/edinburgh/9781474435536.001.0001.

Gambarotto, Andrea. "Teleology and Mechanism: A Dialectical Approach." *Synthese* 201, no. 5 (2023): 155. https://doi.org/10.1007/s11229-023-04137-y.

Georgescu-Roegen, Nicholas. *The Entropy Law and the Economic Process*. Cambridge, MA: Harvard University Press, 1971.

———. “The Entropy Law and the Economic Process in Retrospect.” *Eastern Economic Journal* 12, no. 1 (1986): 3–25.

Hegel, Georg Wilhelm Friedrich. *Philosophy of Mind*. Translated by A.V. Miller and W. Wallace. New York, NY: Oxford University Press, 2007.

———. *Philosophy of Nature: Part Two of the Encyclopaedia of the Philosophical Sciences*. Translated by A. V. Miller. With Foreword by J. N. Findlay. Oxford, UK: Oxford University Press, 2004.

———. *The Phenomenology of Spirit*. Cambridge, UK: Cambridge University Press, 2018.

———. *The Science of Logic*, edited by George Di Giovanni. Cambridge, UK: Cambridge University Press, 2010.

Illetterati, Luca. “Nature, Subjectivity and Freedom: Moving from Hegel’s Philosophy of Nature.” In *“I That Is We, We That Is I.” Perspectives on Contemporary Hegel: Social Ontology, Recognition, Naturalism, and the Critique of Kantian Constructivism*, edited by Italo Testa, 183–201. Leiden: Brill, 2016. https://doi.org/https://doi.org/10.1163/9789004322967_012.

———. “Nature’s Externality: Hegel’s Non-Naturalistic Naturalism.” Edited by Mladen Dolar. *Problemi* 58, no. 11–12 (2020): 51–72.

Kant, Immanuel. *Critique of Judgement*. New York, NY: Macmillan, 1892.

Lemmens, Pieter. “Love and Realism.” *Foundations of Science* 22, no. 2 (2017). https://doi.org/10.1007/s10699-015-9471-6.

Longo, Giuseppe, and Maël Montévil. “From Physics to Biology by Extending Criticality and Symmetry Breakings: An Update.” *Acta Europeana Systemica* 9 (2020). https://doi.org/10.14428/aes.v9i1.56043.

———. *Perspectives on Organisms: Biological Time, Symmetries and Singularities*. Berlin and Heidelberg: Springer, 2014. https://doi.org/10.1007/978-3-642-35938-5.

Magrì, Elisa. “The Place of Habit in Hegel’s Psychology.” In *Hegel’s Philosophical Psychology*. London and New York: Routledge, 2016.

Malabou, Catherine. *The Future of Hegel: Plasticity, Temporality and Dialectic*. *The Future of Hegel: Plasticity, Temporality and Dialectic*. London and New York: Routledge, 2005. https://doi.org/10.4324/9780203489338.

Maréchal, Kevin. "An Evolutionary Perspective on the Economics of Energy Consumption: The Crucial Role of Habits." *Journal of Economic Issues* 43, no. 1 (March 1, 2009): 69–88. https://doi.org/10.2753/JEI0021-3624430104.

Montévil, Maël. "Entropies and the Anthropocene Crisis." *AI and Society*, 2021. https://doi.org/10.1007/s00146-021-01221-0.

Montévil, Maël, and Matteo Mossio. "Biological Organisation as Closure of Constraints." *Journal of Theoretical Biology* 372 (May 7, 2015): 179–91. https://doi.org/10.1016/j.jtbi.2015.02.029.

Odling-Smee, F. John, Kevin N. Laland, and Marcus W. Feldman. *Niche Construction: The Neglected Process in Evolution*. Princeton, NJ: Princeton University Press, 2003.

Paolo, Ezequiel Di. "The Enactive Conception of Life." In *The Oxford Handbook of 4E Cognition*, edited by Albert Newen, Loen De Bruin, and Shaun Gallagher, 71–94. Oxford, UK, 2018.

Plato. *Phaedrus*. Translated by Harvey Yunis. Cambridge, UK: Cambridge University Press, 2011.

Rietveld, Erik, Damiaan Denys, and Maarten Van Westen. "Ecological-Enactive Cognition as Engaging with a Field of Relevant Affordances: The Skilled Intentionality Framework (SIF)." Edited by Albert Newen, Leon De Bruin, and Shaun Gallagher. *The Oxford Handbook of 4E Cognition*. Oxford, UK: Oxford University Press, September 13, 2018. https://doi.org/10.1093/oxfordhb/9780198735410.013.3.

Rosendal, Søren. "The Logic of the 'Swamp World': Hegel with Kafka on the Contradiction of Freedom." In *Kafka and the Universal*, edited by Arthur Cools and Vivian Liska, 66–89. Berlin and Boston: De Gruyter, 2016. https://doi.org/doi:10.1515/9783110458114-004.

Schneider, Eric D., and Dorion Sagan. *Into the Cool: Energy Flow, Thermodynamics, and Life*. Chicago, IL: University of Chicago Press, 2005.

Schrödinger, Erwin. *What Is Life? The Physical Aspect of the Living Cell*. Cambridge, UK: Cambridge University Press, 1944. https://doi.org/LK - https://worldcat.org/title/499840714.

Schwartzman, David. "The Limits to Entropy: Continuing Misuse of Thermodynamics in Environmental and Marxist Theory." *Science and Society* 72, no. 1 (2008): 43–62. https://doi.org/10.1521/siso.2007.72.1.43.

Seddone, Guido. *Hegel's Theory of Self-Conscious Life*. Leiden: Brill, 2022. https://doi.org/https://doi.org/10.1163/9789004527638.

Sève, Lucien. "Dialectics of Emergence." In *Dialectics for the New Century*, edited by Bertell Ollman and Tony Smith, 85–97. New York, NY: Palgrave Macmillan, 2008. https://doi.org/10.1057/9780230583818.

Stiegler, Barbara. "1880: First Philosophical Critique of Adaptationism Nietzsche, Reader of Herbert Spencer." In Naturalism and Social Philosophy: Contemporary Perspectives, edited by Martin Hartmann and Arvi Särkelä, 65–79. Essex Studies in Contemporary Critical Theory. Lanham: Rowman & Littlefield, 2023.

Stiegler, Bernard. *States of Shock: Stupidity and Knowledge in the Twenty-First Century*. Translated by Daniel Ross. Cambridge, UK: Polity, 2015.

———. *The Age of Disruption : Technology and Madness in Computational Capitalism*. Translated by Daniel Ross. Reprinted. Cambridge, UK: Polity, 2019.

———. *Technics and Time, 1: The Fault of Epimetheus*. Translated by Richard Beardsworth and George Collins. Stanford, CA: Stanford University Press, 1998.

———. "The Neganthropocene." Translated by Daniel Ross. London, UK: Open Humanities Press, 2018.

Stone, Alison. "Hegel, Naturalism and the Philosophy of Nature." *Hegel Bulletin* 34, no. 1 (May 1, 2013): 59–78. https://doi.org/10.1017/hgl.2013.2.

Sultan, Sonia E. *Organism and Environment: Ecological Development, Niche Construction, and Adaption*. Oxford University Press, 2015.

Ulanowicz, Robert E. “Beyond the Material and the Mechanical: Occam’s Razor Is a Double-Edged Blade.” *Zygon®* 30, no. 2 (1995). https://doi.org/10.1111/j.1467-9744.1995.tb00068.x.

Ulanowicz, Robert E. “Socio-Ecological Networks: A Lens That Focuses Beyond Physics.” *Frontiers in Ecology and Evolution*, 2021. https://www.frontiersin.org/articles/10.3389/fevo.2021.643122.

Uller, Tobias, and Heikki Helanterä. “Niche Construction and Conceptual Change in Evolutionary Biology.” *British Journal for the Philosophy of Science* 70, no. 2 (2019). https://doi.org/10.1093/bjps/axx050.

White, Joel. “Outline to an Architectonics of Thermodynamics: Life’s Entropic Indeterminacy.” In *Contingency and Plasticity in Everyday Technologies*, edited by Natasha Lushetich, Iain Campbell, and Dominic Smith, 183–200. New York and London: Rowman & Littlefield, 2022.

Zwart, Hub. “Friedrich Engels and the Technoscientific Reproducibility of Life.” *Science and Society : A Journal of Marxist Thought and Analysis* 84, no. 3 (2020): 369–400.