

THERMODYNAMICS, ECONOMIC EVOLUTION AND GROWTH OF INFORMATION: THE PERSPECTIVE OF PEIRCEAN SEMIOTICS

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ABSTRACT

Relating thermodynamics and economics has been mainly achieved by investigating thermodynamic constraints on growth and the role of energy. The economic connection between energy and information remains neglected because physical concepts of information are mostly informed by the Shannon view, which downplays the semantic dimensions of information. I argue that a synthesis of thermodynamics and economics must build on a new approach to the physics of information which can be achieved by semiotics as framed in the philosophy of Charles S. Peirce and in modern biosemiotics. Rethinking causality is pivotal, especially with reference to final causes in evolutionary processes. If final causes are recognized as a physical concept, the growth of information is an embodied form of inference mediated by semiosis. The correspondence in thermodynamics is the Maximum entropy hypothesis which is employed both as a formalism of inference and as a physical mechanism of energy dissipation. I present a conceptual frame and apply this on 'design' as bridging engineering and economics in technological evolution.

Keywords: information; Maxwell's demon; Maximum entropy; technological evolution

1. INTRODUCTION

The concept of information is central to modern economics. However, with few exceptions, information is treated as disembodied. For example, modern growth theory recognizes that new knowledge must be produced, but its contribution to growth works via positive externalities which are 'just in the air'. In fact, the generation of those externalities is why cities exist, which requires huge energy feeds.

One deeper reason for this view is that the thermodynamic aspects of information are blanked out. There are two ways how thermodynamics is employed in economics: One is the application of classical thermodynamics in studying energetic transformations (mostly in ecological economics), the other is

analogical modelling of the economy by defining correspondences between physical concepts and economic concepts (mostly in econophysics). The formal homology between entropy and Shannon information implies a concept of information that is merely quantitative and does not consider the semantics of information. In this paper, I sketch a conceptual approach to the semantics of information that is physical. I go back to the pragmatist tradition in philosophy, namely Charles S. Peirce's semiotics. In a nutshell, this tradition highlights what information 'does', i.e. equates meaning and function. Function can be conceived in both physical and economic terms.

In simplest terms, I argue that the Shannon concept of information and the semantics of information can be synthesized in a physical theory of information by stating, first, that Shannon information is a measure of complexity, and second, that growth of complexity is a physical means of maximizing entropy production. I show that Peirce's semiotics allows for developing a philosophical and conceptual basis for developing a semantics of information that ties up with maximum entropy thinking, in principle. My rhetorical workhorse is a new interpretation of Maxwell's demon, to simplify a complicated argument, given spatial limitations (which is fully developed in [10]). I demonstrate the relevance of this approach for economics in sketching a semiotic view on technology.

2. LITERATURE

The dissociation of information and thermodynamic approaches to the economy originated with Georgescu-Roegen [1]. He declared statistical thermodynamics as irrelevant and concentrated on classical energetic transformations. The question was re-opened in a fresh and promising way by Robert Ayres [2]. He explicitly distinguished between two types of information, 'distinguishability' D-Information and 'survival-relevant information' SD-Information, thus establishing the direct connection to the concept of evolution which also crucial in my argument. However, Ayres could not resolve the problem how to define SR information in physical terms, and in his later

work concentrated on growth and energetic transformations, thus effectively falling back on the Georgescu-Roegen track. This is also true for other physics approaches, such as Kümmel's [3] important work. Regarding information, the Shannon view remains most influential, mostly in terms of a generic notion of 'complexity'. as in Hidalgo's [4] inspiring book, which explicitly argues that growth of information is a physical necessity in non-linear non-equilibrium systems but retreats to complexity and related measures when discussing the economy.

To my best knowledge, Peirce has been rarely invoked when considering the relationship between thermodynamics and economic evolution, despite important contributions to ecological economics that relate to pragmatism as a philosophical basis for policy design [5]. Peirce's thinking was deeply shaped by the two scientific revolutions of his times, Darwinism and thermodynamics [6]. One of the few scholars who explored this facet of Peirce is the biologist Stanley Salthe [7], who posited that meaning and function are two sides of one coin, and that in evolutionary systems, function can be referred to ultimate purposes of evolutionary processes, which is the maximization of entropy production. Salthe developed mathematical approaches together with the physicist Arto Annala [8], and the Peircean conceptual framework was developed together with Herrmann-Pillath [9] who extended it to economics [10].

My argument comes closest to Deacon's [11] radical rethinking of physical foundations for understanding the mind. Deacon argues, same as Salthe, that for a proper physical understanding of information, we must eschew the common idea that the physical exclusively refers to efficient causes and must include the full range of Aristotelian types of causes, final and formal. This is what I am going to explore now.

3. MAXWELL'S DEMON, 2.0

Ayres' notion of SD-information means that what is information is determined by its functions in 'survival', i.e. its contribution to ultimate criteria of selection. Functions, as proximate causes, are defined relative to a specific context in which proper realization of function results in meeting ultimate selection criteria, such as successfully foraging to meet the organismic needs for energy invested in reproduction.

John Searle [11] has argued that functions are always 'observer-dependent'. However, whereas he championed a mentalist view on observation, I suggest the opposite: Interpreting 'observers' as physical systems, as suggested in foundational physics approaches [12]. In the history of thermodynamics, there is a famous metaphor that explicitly considers an observer, namely Maxwell's demon. The original intention of the parable was to discuss the possibility that a hypothetical demon may be able to sort the molecules of a gas in a container while violating the Second Law. Significant in our context, this was grounded in the demon's capacity for information processing: The demon would just move a separator, given information about speed and location of molecules, and thereby select molecules into two parts of the container, one

hotter, one cooler. This means, via the sorting, the demon would create the capacity for generating physical work.

The parable generated a fruitful discussion in physics and philosophy that revealed the physical nature of information processing [14]. In a nutshell, the various contributions converge on that in considering the information-theoretic aspects of the demon, we must distinguish between the amount of information processed and how it is processed, the information embodied in the distribution of molecules, and the growth of complexity of the information storage. The demon cannot operate without expending energy in some stages of information processing, including the erasure of obsolete information, given the trade-off with growing energy needs for physical storage. Indeed, the parable unveils all conceptual components necessary for understanding the physical aspects information in the contexts of economics: A technological device that generates the capacity for work, the crucial role of information to make it work, and an intelligent agent that operates the device.

In the discussion, information is treated as Shannon information, via the Boltzmann homology. I suggest an alternative conceptual frame, biosemiotics, as distinguishing between object, observer and the sign as mediating entity, and adding evolution as the ultimate force that shapes this relationship [15]. Observation is a physical process in which the object impacts efficient-causally on the observer, such as the photon impact on the eyes. However, this is not information. Data processing is costly, so that natural selection would favor focusing on those data which are significant, which means which have a function. This is the point where final causes come into play: Information is about fulfilling a function that emerged evolutionarily.

The interaction between object and observer is mediated via signs. For example, snakes are dangerous for rabbits, and hence the rabbit develops the capacity to recognize indicators of snakes, such as a pattern of movements, and will neglect other properties. The sign is what causes the action, such as running away. The mere efficient-causal impact cannot explain why the rabbit takes this action; despite we can say that the impact causes the action. This is the point where the conjunction of function and meaning of the sign emerges. The observer acts as 'interpretant': Interpretation is a semantic category, but is conceived in physical terms, in the sense of the action generated by the sign which fulfills a function.

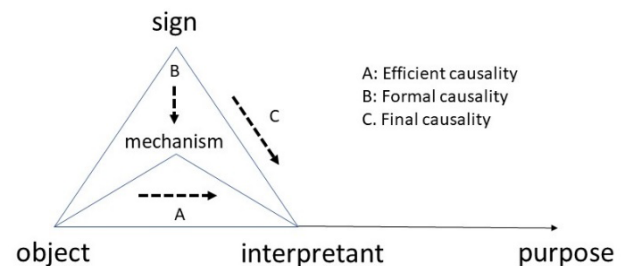


FIGURE 1: BASIC SEMIOTIC TRIAD (UNIT OF SEMANTIC INFORMATION)

We can summarize this reasoning in terms of the semiotic triad that depicts the relationship between three different forms of causes: (a) *Objects* relate with interpretants both efficient-causal mechanisms and mediated by signs ('bimodality' in [10]). (b) *Signs* select efficient-causal impacts on the interpretant in terms of categorization. This corresponds to the notion of formal causality. (c) *Interpretants* retrieve functionally relevant information about objects from signs. The information triggers actions that fulfill functions, thus manifesting final causality. The triad is what constitutes the *unit of semantic information*.

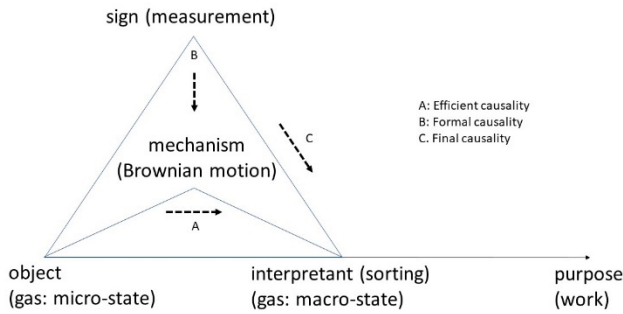


FIGURE 2: THE DEMON'S SEMIOSIS

If we apply this conceptual frame on the demon (fig. 2), measurement is the sign that relates to the microstate of the gas molecules. However, what is missing in the parable but is crucial for the semiotic interpretation is the purpose of the sorting. The purpose is to produce work, and we might even posit, to connect directly to the evolutionary framework, that this work sustains the demon's operations: That is, the demon, now version 2.0, would be conceived as an 'autonomous agent' in the sense of Kauffman [16], i.e. a system that realizes recurrent thermodynamic work cycles via information processing. One important consequence is that the demon could be satisfied with less precise measurements ('coarse graining'), such as determining minimum thresholds in categorizing molecules into the two classes that represent the two parts of the container, which introduces economy of information.

4. ENTER MAXIMUM ENTROPY

Fig. 3 details the aspect of economy of information in terms of transformations of information. This follows Peirce in considering that interpretant action can be a sign in turn. Figure 3 establishes the connection between the levels of statistical and classical thermodynamics in distinguishing between micro- and macro-states and in assuming that considering the function of the sorting, the demon 2.0 can focus on macro-states when generating work. That is, the sorting results in a loss of information because once it is accomplished, the demon would no longer measure the micro-states and could never recover the original micro-states. But it measures the macro-states, i.e. the temperature difference which conditions the capacity to generate work. Hence, there are not only ongoing energetic transformations, but also transformations of information. Transformations of information and of energy are two sides of

one coin, which establishes the conceptual bridge to the economics of information.

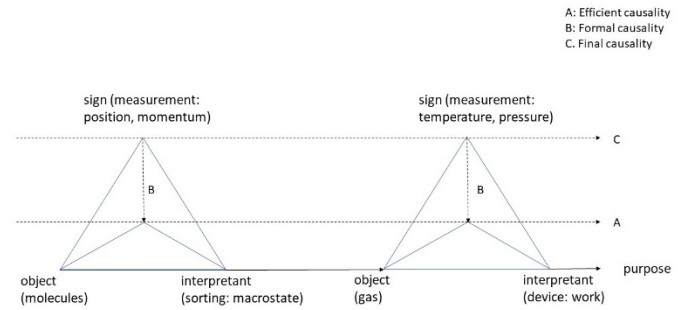


FIGURE 3: INFORMATION TRANSFORMATION

For better understanding the thermodynamic aspects of information transformation, the Maximum entropy framework is promising, which has two different versions: One, as introduced originally by Jaynes [17], is to approach MaxEnt as an inference procedure, and the other is to refer this to actual physical processes of entropy production (MEP: Maximum Entropy Production) [18]. The connection between the two was first established in the Earth system sciences [19]: In investigating a complex system, the most parsimonious approach is to identify constraints that determine its evolution, and otherwise posit that the state of the system assumes the most probable state, i.e. maximizes entropy in information-theoretic terms. The constraint is what the observers suggests as a hypothesis. If the MaxEnt test fails, the hypothesis must be corrected. MEP posits that complex systems factually evolve under constraints by maximizing physical entropy production.

We can refer this directly to the semiotic triad: MaxEnt is equivalent to Peirce's notion of abduction as the only inference procedure that can lead to new information. This reflects a two-sided role of the sign in the triad: The sign relates causally to the object but is 'as-signed' by the interpretant. The sign is a hypothesis in the sense that, for example, the rabbit would guess that a certain pattern of movement represents a snake, and if this is correct, would assume functional action, i.e. fleeing.

Returning to the demon 2.0, I extend the parable (Fig. 4). Let us assume a population of many demons as autonomous agents which compete against each other in terms of their capability to perform work via demons' various sorting devices. The output of the sorting, generation of work, determines the rate of reproduction of types of demons. At this point, Lotka's [20] Maximum power theorem comes into play: Those demons with most energy throughput will succeed best in natural selection of demons. Designing an efficient measurement mechanism is a crucial determinant of reproductive success. Hence, demons will develop procedures that economize on the energetic expenditures for information processing; MaxEnt is the underlying principle of inference. Since to maximize power throughput is the ultimate criterion for reproductive success, MEP emerges as ultimate function of the process. MPP and MEP only emerge on the population level, i.e. single demons can fail to manifest these principles, which is exactly what natural

selection implies. However, via MaxEnt demons will converge on an efficient inference procedure which implies convergence of signs aka constraints as hypothesized by demons 2.0. Therefore, information is a population-level phenomenon, though embodied in physical tokens.

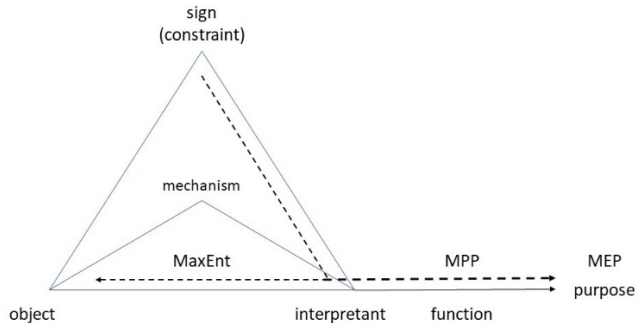


FIGURE 4: SEMIOSIS AND ENTROPY PRODUCTION

5. DESIGN AND ENTROPY PRODUCTION

We can take the demon's 2.0 as a framework for understanding technological evolution as growth of information by entropy production. Technology evolves via exploring an originally unknown world of physical effects which are related to functions, i.e. in proximate terms, human uses of technological artefacts [21]. I suggest that the crucial connection between the physical objects and the uses is design: In the semiotic view, design is a sign that mediates mechanism and function, and that also allows users to develop hypotheses about the possible uses of mechanisms. This corresponds to the new demon's parable in approaching measurement as a technology.

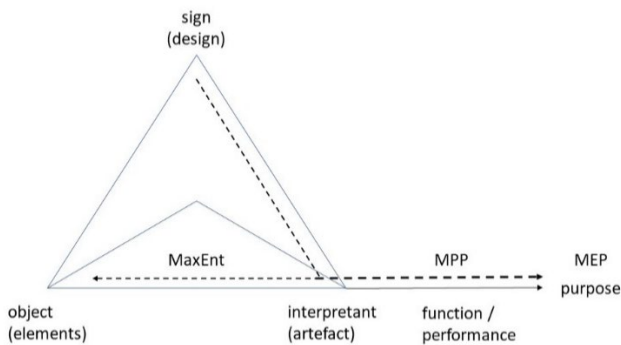


FIGURE 5: TECHNOSEMIOSIS AND ENTROPY PRODUCTION

Technological evolution is a population-level phenomenon in constantly generating many design variants that compete over the unknown world of object qua physical mechanisms. Designs will assume states which most effectively dissipate energy and hence maximize entropy.

6. CONCLUSION

The physical concept of information as semiosis suggested here has far-reaching consequences for our understanding of

economic growth: Whereas in the Georgescu-Roegen tradition thermodynamics is referred to as constraint on growth, we can now say that growth is a physical mechanism of maximizing entropy production by means of the growth of information. By implication, it is wrong to assume that growth of information could overcome thermodynamic constraints on growth.

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