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The Evolutionary Approach to Entropy: Reconciling Georgescu-Roegen's Natural Philosophy with the Maximum Entropy Framework

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Abstract

In Georgescu-Roegen's classical, though controversial discussion of entropy in relation to economics, the dualism of mechanical and subjective time plays a pivotal role. I argue that this fundamental distinction also inheres modern approaches to maximum entropy. Following Searle, I introduce the ontological dualism of observer independent and observer relative facts, and show that the notion of entropy also manifests this dualism, in the sense of the contextuality of measurements in experimental settings. Extending on the notion of observer relativity, I argue that the MaxEnt principle can be generalized into a framework of analyzing the evolution of (biological, technological etc.) functions under natural selection, if functions are equated with inference devices. Then, observer relativity is function relativity. In hierarchical evolutionary systems, this corresponds to the Maximum Entropy Production Principle, in the sense that functional evolution approximates gradients of maximum dissipation of energy. Against this background, the Georgescu-Roegen dualism of time translates into the dualism of observer independent entropy, which is the object of MEPP, and observer relative entropy, which is the object of MaxEnt. Both are two aspects under which evolution in general and economic evolution in particular can be analyzed.

Key words: Georgescu-Roegen, maximum entropy, observer relativity, time, hierarchical evolutionary systems, natural selection, physical concepts of information

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Content

1 The problem of the contextuality of entropy: Fertile ground for the reconciliation of Georgescu-Roegen's views with modern approaches

Since Georgescu-Roegen's (1971) seminal contribution to evolutionary economics, the debate over the possible role of the concept of entropy for the foundations of economics in general and ecological economics in particular has been raging on uninterruptedly (see e.g. Gillett 2006 vs. Lozada 2006). Georgescu-Roegen remains very influential in both his achievements and his mistakes. An important part of his legacy for ecological economics is the focus on phenomenological thermodynamics and the related issues of energy and entropy, which are directly pertinent to environmental challenges, on first sight. This also implies a close affinity with the engineering perspective on thermodynamics, as environmental problems are mostly engineering problems under economic constraints. This focus mostly leads to the conclusion that entropy is an analytical category of a degree of abstraction that renders it useless for economics (Bünstorf 2004: 25ff.), and, if taken seriously in its physical meaning, irrelevant for economic analysis because of the sheer difference in magnitudes that exist between entropic processes of the earth system and the entropic processes of man-made systems.

I think that this conclusion is premature, because one challenge is still open. This is to reconcile the thermodynamic use of entropy and the information theoretic use, which has been achieved for long in the general mathematical treatment of entropy (surveyed e.g. by Niven 2007). Both have been scrutinized by Ayres (1994) in his seminal contribution, and Ayres had already developed two important insights, starting out from an observation that directly matches with Georgescu-Roegen's original qualms with statistical mechanics: This is that information is an *intensive* (hence, qualitative, or dialectic variable, in Georgescu-Roegen's parlance), whereas entropy in thermodynamics is an *extensive* variable (Ayres 1994: 36). One of Ayres' insights is that there is a direct physical relation between Shannon information H and thermodynamic magnitudes, because the former can be interpreted as a general measure of distinguishability of a system from its environment. The other is to distinguish between this thermodynamic concept of information (D-information in his terminology) and the evolutionary one, which is survival relevant information. The latter refers to a selective context in which certain information proves to be functional with reference to differential reproduction.

In my mind, this distinction does not make full use of the observation that in the case of distinguishability, entropy is also a contextual magnitude, which is only made commensurable via reference to standardized environments. So, both kinds of entropy are contextual, but in different ways. The contextuality of entropy also underlies all economically relevant uses of energetic concepts, which build on the notion of exergy, or potential useful work, relative to a particular environment of a system. I think that this observation paves the way to reconcile Georgescu-Roegen's perspective with the modern view on entropy.

This reconciliation can be most straightforwardly achieved if we make full use of the Jaynes approach to entropy, which is still neglected in economics (compare Ruth 2005). This approach has gained in prominence with the recent rise of Maximum Entropy concepts in physics, especially in the earth sciences (Whitfield 2005; Kleidon 2009, 2010). It builds on the statistical mechanics foundation of thermodynamics, and seems therefore plainly incompatible with Georgescu-Roegen's critique of Boltzmann. But a closer look shows that one of Georgescu-Roegen's central ideas, the distinction between arithmomorphic and qualitative theories, can be reconciled with the Jaynes's view. This is possible if we start out from one of Georgescu-Roegen's most fundamental points, namely the distinction between time as a mechanical phenomenon and time as a subjective experience (Georgescu-Roegen 1971: 132ff.). Subsequently, I show that this distinction can be given more analytical precision if we introduce the two notions of observer independent and observer relative entropy, and show that evolution is a two-sided phenomenon, both manifesting the linear growth of observer independent entropy according to the Second Law, and the sequence of incommensurable observer relative entropies, which reflect structural novelty of the state space in which evolution proceeds. By this conceptual innovation, which builds on earlier contributions such as Salthe's (1993) distinction between internalist and externalist measures of entropy, I also hope to offer a unifying framework for Ayres' distinction between D-information and S-information. I think that this distinction becomes obsolete if we distinguish between the two complementary concepts of entropy, such that we arrive at an evolutionary conception of entropy, which then effectively bridges between Georgescu-Roegen's natural philosophy and the modern view.

I proceed as follows. In section 2, the main part of the article, I discuss the two versions of the maximum entropy approach, MaxEnt as an inference method, and MEP as a physical theory about open non-equilibrium systems. I offer a conceptual unification by evolutionary theory. In section 3 I discuss how this can be related to Georgescu-Roegen's notion of time. Section 4 shows the relevance for ecological economics. Section 5 concludes.

2 Maximum Entropy, observer relativity and evolution

2.1 Observer relative and observer independent facts

The current debate over the Maximum Entropy principle girates around the distinction between the MaxEnt principle and the Maximum Entropy Production Principle (MEPP). The MaxEnt Principle directly follows from statistical mechanics and interprets entropy as a lack of information on part of an observer. MaxEnt just states that an observer should assume the most probable distribution of an partly unkown set of events over a state space, given certain constraints. The MEP principle relates with phenomenological thermodynamics and refers to the physics of energy flows, thus introduces the additional assumption that the observed physical system will realize the most probable state. It is an open issue whether the two principles are ultimately the same physical propositions, or, whether MaxEnt necessarily implies MEPP. Therefore, I discuss the two in turn.

However, before doing that, it is necessary to introduce the distinction between observer independent (OI) and observer relative (OR) facts, that has been made a cornerstone of naturalistic ontology by Searle (Searle 1995, 2004). An observer independent fact is a fact that exists without relation to an act of observation, such as a rock or a tree. An observer relative fact is a fact that only exists because there is an observer. This includes all what philosophers call qualia, such as pain, but also a vast domain of social and cultural facts, such as money or a fence. Entities can have both properties: The fence exists independent from an observer, but even if it is easy to climb, it becomes an almost insurmountable barrier as a legal fact, which is observer relative.

Two additions to Searle's original conception are necessary for my treatment of entropy.

Firstly, Searle mainly thinks of human observers, and hence relates OR facts to mental phenomena. In a consistent naturalistic approach, this is far too narrow, as it seems evident that all living systems manifest processes of observation, as when a bacterium screens its environment for nutrients (Ben Jacob 1998, Ben-Jacob et al. 2006). We can formulate more abstractly that any process which generates information is an observation, which turns this concepts into a special category of causality, namely a function (for an early related view, see Bateson 1979). This is the approach taken in teleosemantics, which reduces all mental phenomena (that is, intentionality and meaning) to functions (Dretske 1981, Millikan 1989, MacDonald and Papineau 2006, Neander 2009). So, for example, a thermometer observes its environment, because it generates information that is part of a function, such as regulating a heating system, in a basically similar way as the human skin does, ultimately regulating human behavior directed at thermoregulation. Further, the process of observation can have different levels of aggregation. For example, we might think of our skin as a part of our body that observes the temperature of an object, or we might conceive of an entire ecosystem as an aggregate observer of the temperature of an object. In particular, observations can be manifested in evolving populations of systems with functions, as in the case of species-specific systems of perception and behavioral control.

Secondly, all facts of science are OR facts, because they relate with a human observer using a complex symbolic language. This holds true even though they are intended to describe OI facts. Yet, we have to distinguish between concepts that are explicitly intended to refer to OI facts (though being OR facts on basic philosophical grounds), and those concepts that explicitly refer to an observer.

I claim that these distinctions suffice to reconcile Georgescu-Roegen's approach with modern physical approaches to entropy, because he relates the distinction between arithmomorphic and qualitative concepts with the existence of an observer, especially in his discussion of the reference frame of time, where he distinguishes mechanical time and the arrow of time which is rooted in subjective experience. In our context, this introduces the distinction between OI and OR time.

Armed with this conceptual distinction, I can now introduce the fundamental difference between observer relative Entropy_{OR} and observer independent Entropy_{OI}. I posit that the current distinction between MaxEnt and MEP corresponds to these two entropies, respectively, and that this resolves the Georgescu-Roegen dilemma.

2.2 Evolution conditions MaxEnt and manifests Maximum Entropy Production

2.2.1 MaxEnt: A principle of selection

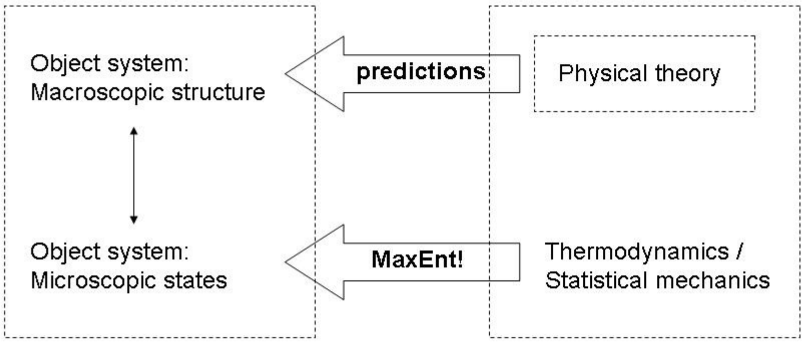
In economics so far, the MaxEnt principle has only exerted a strong impact on econometrics because it is basically an inference principle. Dewar (2009) has argued recently, that, as inference principle it has a much broader and principled role in the theory of entropy and in physics generally (see also the original statement by Jaynes 1998). The original Gibbs-Jaynes approach treated entropy as a measure of ignorance on part of the observer of a system. The entropy of a system, in this case directly using the Boltzmann formula, is the maximum number of microstates compatible with a set of macrostates, given certain constraints on the system. The MaxEnt principle states that in predictions of macrostates, the observer should choose those states in which the related microstates manifest the maximum entropy, i.e. are the most probable ones.

This entropy is not an absolute value, because it depends on the constraints on the macrostates. As Jaynes (1965) has demonstrated forcefully, entropy – in Searle's notation – is an observer relative magnitude, because it depends on the setting of macrostates and the constraints. In physics, these are experimental settings which depend on the choice of a theory and the pertinent physical variables. Thus, in Jaynes' own example, the entropy of a crystal is different depending on whether one considers temperature, pressure and volume, or when one considers temperature, strain and polarization. Hence, Jaynes concluded that entropy is an anthropomorphic concept. In Niven's (2007) parlance, the underlying notion of an ensemble is a mental phenomenon, that is, it is an OR fact.

In Dewar's (2009) view, this approach can be turned dynamic in the sense of generalizing over the MaxEnt principle as an estimation technique (fig. 1). In this case, the macrostates correspond to conjectures about the kind, number and structure of macrostates with constraints which are necessary to predict the future change of a system. The MaxEnt principle then simply states that those constraints are identified as the causally relevant ones, at which the entropy of the microstates is maximal. If the latter fails to prove, the constraints have to be changed. Thus, MaxEnt is not a physical principle on its own, but only a theoretical and methodological concept that allows to identify the physically relevant constraints on a system.

Fig. 1: The MaxEnt principle

A complex system is differentiated into macroscopic states and microscopic states. Future macroscopic states are predicted by choosing the maximum entropy microstates, given the constraints on the system.



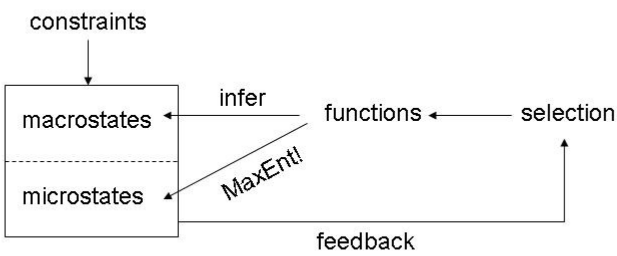
Thus, it is straightforward to recognize that MaxEnt establishes an observer relative notion of entropy, as the choice of macrostates and constraints depends on the interests of the observer, that is, which kind of physical change is in focus. This explains the formal homology with Shannon entropy as a measure of information, in which observer relativity is constitutive, i.e. depending on arbitrary partitions of the state space, which ultimately depend on the interests of the users of a code to convey a message. Therefore, the question is whether we can formulate a general notion of observer relativity and apply this on MaxEnt. This is indeed possible if we interpret Dewar's methodological view in the more general horizon of evolutionary epistemology, i.e. interpret MaxEnt as a feature of evolving information processing systems under natural selection (Popper 1972, Bradie and Harms 2008).

As I posited previously, this can be achieved by introducing the notion of a function. We can say that the determination of the macrostates and the constraints depends on the function of the chosen macrostates in the system into which the physical process of observation is embedded. In Dewar's view, those functions are the physical theories which are supposed to provide guideposts for successful experimental actions. Following evolutionary epistemology and teleosemantics, we can generalize this idea into a naturalistic approach to observation, such that we can say that functions are the result of natural selection. In this view, any biological, technological and other function is a generalized inference device which links a mechanism of prediction with an action that produces causal effects that are relevant in a selective context (for a related approach, see Dennett 1995; on a universal concept of an inference device, see Wolpert 2008). That is, the most general purpose inhering a function is the contribution to differential reproduction of the system of which the function is a part. I am aware of the fact that this is a contentious statement of its own, opening up the Pandora's box of the perennial debates over Darwinism, but I ask the kind reader to accept this as a provisional, relatively safe point of departure.

The central insight is that this means that the determination of macrostates is an evolutionary phenomenon, in the sense that the functions of the embedding systems evolve. The interpretation of the MaxEnt principle is straightforward in this context (see fig. 2). If Dewar argues that the MaxEnt principle is a way of testing physical theories and adapting them to an unknown and complex reality, we can now say that MaxEnt is criterion of selection in a complex evolutionary process. In other words, if MaxEnt fails, an observation of an object system fails to cause proper functioning of an observing system because there is a feedback mechanism that reveals that some important constraints on the object system have not been sufficiently included into the function. In contrast, the actualization of MaxEnt means that the observing system has attained a level of functioning in which all other information, beyond the information about the macrostates and constraints of the object system, is irrelevant, and can hence be assigned to the equiprobability measure.

Fig. 2: MaxEnt and selection

MaxEnt is a principle of the selection of functions, because a function is an inference device where correct predictions of macrostates of object systems condition proper functioning. Macrostates under constraints are states of systems which are functionally relevant. The optimal predictive performance is achieved if all other microstates of the object system are irrelevant, hence assigned to the MaxEnt state. All relevant information in the constraints and the macrostates has been extracted by the selection of functions.



Dewar (2009) also presents the essential argument why this works: This is the computational efficiency of MaxEnt. A system that approaches MaxEnt economizes on information because if MaxEnt is achieved, there is no need to collect further information beyond the information about the macrostates and constraints. Certainly, computational efficiency and speed is also a central criterion in natural selection. That is, we can hypothesize that natural selection manifests the MaxEnt principle in the sense that all processes of observation will follow the MaxEnt logic. Frank (2009a,b) has recently presented a strong argument in favour of this view in demonstrating that all statistical distributions observed in nature can be reduced to the Max-

Ent formalism (for related arguments, see Grönholm and Annila 2007, or Dewar and Porté 2008). For example, a power law can be explained as a MaxEnt solution in terms of the constraints under which the corresponding process operates. That means, the statistical distributions reflect the information that is necessary for systems functioning in the context of natural selection. All other information is useless, with regard to the proper functioning of the selected systems.

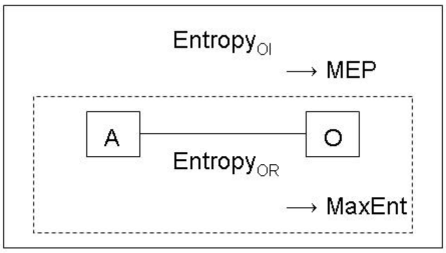
Against the background of these arguments, we can see that the distinction between D-information and S-information introduced by Ayres (1994) becomes obsolete. We can instead argue that the reference frame for D-information is itself the result of evolution, such that S-information and D-information are only two sides of the same coin. Indeed, we might argue that S-information is the observer relative mode, whereas D-information is the observer independent mode of the same underlying physical phenomenon. However, this proposition is only true if we can also give an explication of MaxEnt in terms of MEPP, which stands at the centre of attention in the current debates over the Maximum Entropy approach.

2.2.2 MEPP: The ultimate finality of hierarchical evolutionary systems

The MaxEnt principle does not directly assert that the object system also manifests the state of maximum entropy, but only states that the observing system adopts those representations of the object system in terms of macrostates in which the entropy in terms of the number of possible microstates is maximized, hence the information loss in terms of the proper functioning of the observing system is minimized. The question is, how far does this also imply that the observed system maximizes entropy? This is the hypothesis of Maximum Entropy Production. In asking this question, we switch from entropy_{OR} to entropy_{OI}, because we tacitly suppose that the selection process will approximate a physical reality which is observer independent. This move corresponds to the necessary step in the conceptual foundations of entropy to include always the entire ensemble entropy into entropy analysis, that is, the observed object and the observing system entropy (Zeh 2005). In the argument of section 2.2.1. this means to switch from the function to the entire evolutionary system, into which the observing system is embedded (fig. 3).

Fig. 3: Observer independent and observer relative entropy

The analysis of entropy has to distinguish between the causal relation that exists between an observing system O and an observed object system A, and the embedding system that contains the two systems.



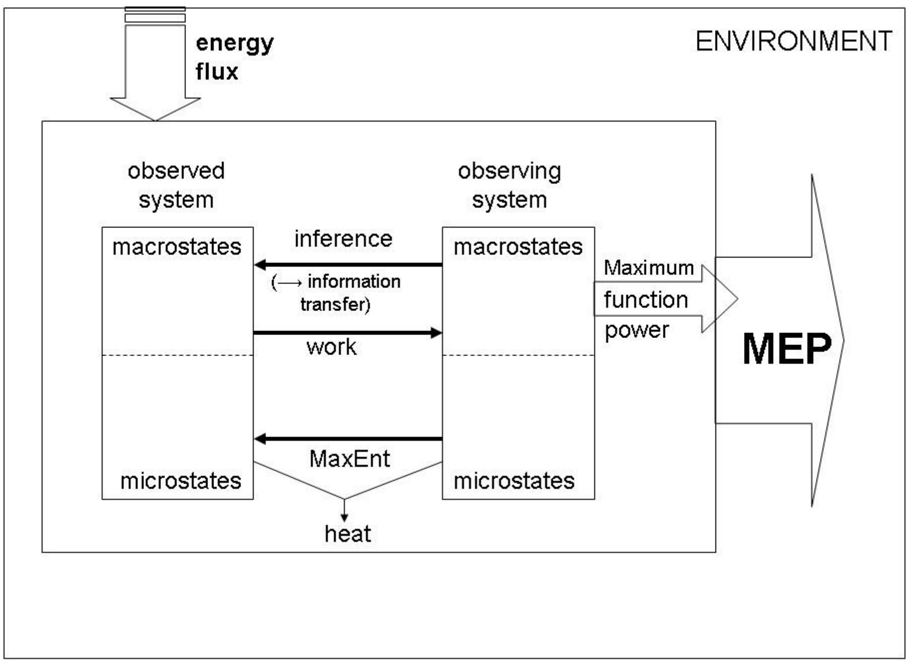
Whether the MaxEnt necessarily implies the MEP principle is an open question in the current debate (Paltridge 2009, Niven 2009). One argument with direct relevance for the Georgescu-Roegen view is presented in the earth sciences. This argument is central because it also establishes a direct connection with Lotka's (1922a,b) conjecture about evolution and natural selection, which states that evolving systems maximize energy flux. Thus, the maximum power principle is treated as a correlate of the MEP principle. This view has been concisely developed by Kleidon (2009, 2010) and states that open non-equilibrium systems such as the earth system will always manifest the tendency to approach the maximum entropy state, which is defined as the macroscopic state which is most probable, given energy and mass-balance constraints. This tendency is empirically complex because the respective manifold processes proceed in vastly different time scales. But the general property of these different processes is that they tend towards a solution to the trade off between forces and fluxes that correspond to the maximum power principle, i.e. the point at which the degradation of a force via the flux obtains a maximum value, taking the reduction of the force by the flux into consideration. Kleidon offers the electric circuit model as a conceptual reference structure, which distinguishes between the generators (of disequilibria), the condensators (states far from equilibrium) and resistors (dissipative processes). Every MEP system can then be analyzed as consisting of two loops, with one depleting a capacitor through time via the dissipation of the resistor, and the other adding a current via a generator, which would obtain a steady state away from equilibrium. So, for example, the energy flows in the sun-earth system can be distinguished into the disequilibrium states, i.e the temperature differences (capacitors), the dissipative processes, i.e. emissions of radiation (resistors) and the processes that drive disequilibrium, i.e. absorption of radiation (generators). These are coupled with other subsystems, such as the carbon cycles or the hydrologic cycles. The MEP principle states that all the dissipating structures in these systems will evolve into states in which the gradients of energy dissipation are the steepest, corresponding to the maximum power principle.

Annila and collaborators have recently shown that the maximum entropy approach can be generalized into the analysis of any kind of hierarchical system in which different levels of energy densities prevail, as in the model case of chains of chemical reactions (Annila and Kusimanen 2009, Annila and Salthe 2010). In this case, the probabilities of different microstates can be directly defined via the thermodynamic gradients between the different levels. The MEP principle states that complex systems will always structurally evolve such that over all levels, the rate of energy dissipation, and hence the ultimate production of entropy, will be maximized.

How can we relate this approach to the more general evolutionary perspective on MaxEnt? I develop the subsequent argument along the structure outlined in figure 4.

Fig. 4: The relationship between MaxEnt and MEP

In a general structure of evolving systems under natural selection, the interaction between observing and observed systems is governed by the MaxEnt principle. The entire system is embedded into the environment via energy throughputs and energy dispersal. Energy dispersal happens via work and heat, with reference to macroscopic and microscopic processes. The actualization of functions under natural selection follows the Maximum Power principle. As a result, the entire system ultimately realizes MEP.



The diagram shows an open system that is embedded into the environment, and which is turn consisting of two systems which stand in the causal relation of observation with each other. This is the most simple form of a hierarchical structure. The observing system manifests a function with reference to the higher-level system, such as an adaptation in an ecosystem. Then, the conjoint hypotheses of MaxEnt and MEP imply:

1. The higher level system receives an energy flux which is dissipated via the causal processes of the lower-level systems on both the macroscopic and the microscopic level.

2. The lower-level observing system relates causally with the object system, such that the observed system transfers energy to the former in the form of work, which involves conjoint changes of macrostates. This change of macrostates of the observing system contributes to the realization of a function.

3. The observing system infers the macrostates of the observed system via the MaxEnt process, which implies maximization on entropy_{OR} with reference to the microstates.

4. Both systems dissipate energy on the microscopic level in the form of heat, concomitant with the macroscopic causal interaction.

5. The function of the observing system maximizes power as a result of the natural selection of functions.

6. The entire, hierarchically nested and causally coupled process maximizes entropy_{OI}.

Adding some more detail to this argument, I think there are two fundamental reasons why we are justified to posit the correspondence of MaxEnt and MEP, beyond the purely mathematical considerations (Niven 2007, 2009). One is an epistemological. Even though we state observer relativity with reference to functions, the underlying causality, which determines proper functioning in terms of selection, is observer independent. This implies that in the underlying physical interaction, the relation between the cause and the effect must manifest a homologous differentiation between the macrostates and the microstates. This applies with special force if we consider natural selection, because in this case we think about a statistical correlation, with evolving populations of systems with functions. If we think of both the object and the observing systems as dynamical systems, their statistical correlation will reflect MaxEnt, which also implies that the causally relevant system manifests MaxEnt. In other words, the causal relation between the observed system and the function of the observing system is a relation that connects macrostates, such that all other causally irrelevant properties of the observed system approximate the maximum entropy state. For example, at a certain point of time the interaction between species is determined by macroscopic behavioral regularities and at the same time there is a maximum of behaviorally neutral individual variation among the members of the species. So, MaxEnt applies for the behavioral interaction based on the generic properties of species, and actual variety on the individual level follows MEP, which, in the course of natural selection, also implies maximum power on the macroscopic level of functions.

The latter part of the previous proposition goes back to Lotka's (1922a,b) conjecture about maximum energy flux in evolving systems (compare Kleidon and Lorenz 2005a, Kleidon 2009). Lotka argues that natural selection will maximize energy flux because this produces performances of living systems that are positively selected by natural selection (for detailed and encompassing overviews of recent generalizations and confirmations, see Vermeij 2004, Odum 2007). If we relate this with the previous discussion of functions, we have to modify this argument by distinguishing between microscopic and macroscopic aspects of the underlying causalities. In this case, the maximum power principle relates to the macroscopic level, in the sense that maximum power is the state in which the respective functions achieve maximum performances in the macroscopic dimensions. In the same way as the MaxEnt principle states that the approximation to the true macroscopic pattern is achieved via the maximization of the entropy of the microstates, the MEP principle states that the maximum power state is achieved on the macroscopic level if microscopic entropy production of the entire system is at the maximum. This establishes the second evolutionary rationale for the correspondence between MaxEnt and MEP. For example, a species will evolve towards the maximization of macro-level properties such as body size, speed of movement, range of action etc., which at the same time implies that these are gradients in the hierarchical structure of the embedding ecosystem along which energy dissipation is maximal, thus ultimately maximizing entropy_{OI}.

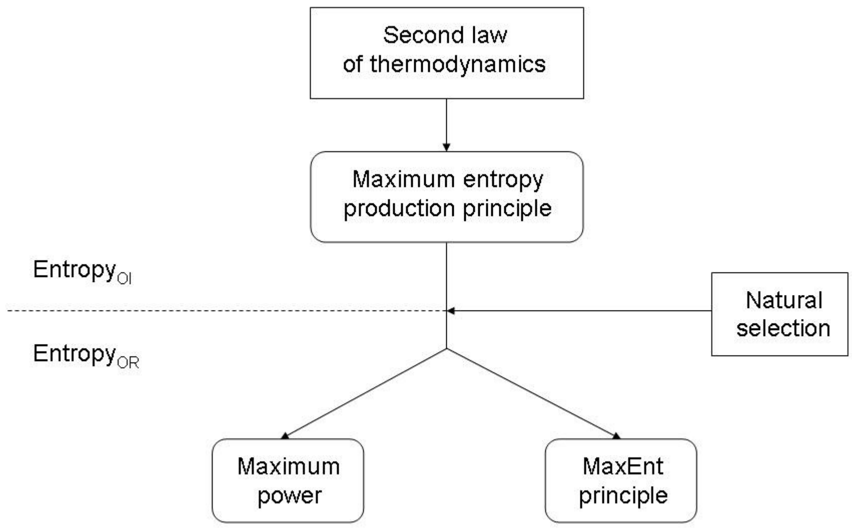
The maximum power principle builds the bridge between MEP and economic applications. This can be shown by analyzing the physical notion of work in terms of the statistical mechanics framework. In the thermodynamics framework, work is defined negatively as all energy transfers between systems that do not directly involve a difference in temperature (Gillett 2006: 59). Positively, in the statistical mechanics framework, work is an energy transfer that changes macrostates, with heat being the energy transfer that changes microstates, given constraints. This definition allows for an interesting switch to the everyday notion of work, which relates to the purposive expense of effort. This can be systematically integrated in the evolutionary framework in which we can define work as an energy transfer that affects a function, hence causally relates macrostates of systems. This energy transfer is the depletion of exergy, given the function by which work is realized. This endogeneity of the notion of work in the evolutionary context (see Salthe 2007) is reflected in the contextuality of the fundamental relation between information, exergy and environment in the thermodynamic view (Ayres 1994: 44ff.). Whereas in more simple physical applications the reference frame can be just defined via the temperature of the environment, the reference frame in case of functions involves structural and morphological features that are much more difficult to determine (Ayres 1994: Chapters 10 and 11).

I briefly sketch these different concepts because they all relate with the fundamental distinction between entropy_{OI} and entropy_{OR}. The MEP does not simply state that entropy_{OI} is maximized, even though this is the final result of all processes that take place e.g. in the earth system. If so, all processes would just explode into heat. However, this is physically impossible, given the constraints of physical laws. Hence, systems evolve into more complex structures in which energy is dissipated in the most rapid and efficacious way, given the constraints. In order to analyze this process, entropy_{OR} is the relevant category. If we argue in the entropy_{OR} context, the concepts of work, power and exergy are relevant. If we argue in the entropy_{OI} context, the concepts of energy and heat are relevant. The two levels are conjoined in the maximum entropy principles. These principles imply a specific relation between observer independence and observer relativity. As we have seen, observer relativity inheres the identification of the constraints under which a system operates, relative to a function. This is why a category such as work both involves the reference to macroscopic levels and to notions of purposiveness. Observer independence inheres the ultimate criterion of entropy maximization, which is tantamount to stating irrelevance of the microstates to the observer.

Fig. 5 summarizes the conceptual relation between the central laws and principles of the maximum entropy view.

Fig. 5: The relation between central concepts of the maximum entropy approach

The Second Law and Natural Selection are the two fundamental hypotheses. The Second Law is the foundation for the MEPP. The natural selection of functions establishes the differentiation between observer independent and observer relative entropy. On the macroscopic level, MEPP is expressed in the Maximum Power principle which relates to functions. The MaxEnt principle relates the macroscopic with the microscopic level.



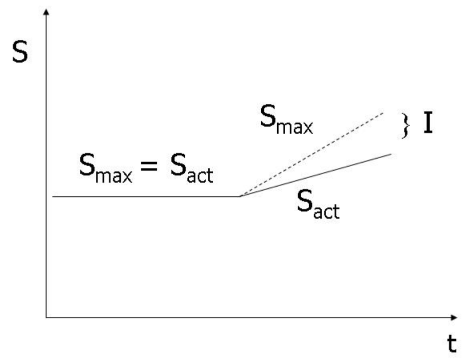
3 The wider ontological setting

In order to relate the results of section 2 with Georgescu-Roegen's two notions of time, I expand into the broader systematic conceptual frame firstly proposed by Layzer (1988) and later developed in more detail by Chaisson (2001, 2005), with another application in biology in the theories proposed by Brooks and Wiley (1988) and Salthe (1993).

The central concept in the statistical mechanics approach is that of the state space. Layzer introduced the distinction between potential, i.e. maximum entropy and actual entropy, which allows to analyze the case of an increasing state space, which is the regular situation in an expanding universe (for a critical view, see Lineweaver 2005). From this follows that in an expanding state space, accumulation of information is possible as long as there is a increasing gap between potential and actual entropy (see figure 6).

Figure 6: Divergent evolution of potential and actual entropy

In the initial state of cosmic evolution, all potential entropy was actual. With the expansion of the universe, the gap between potential and actual increases, because of the constraints on the physical mechanisms in realizing potential states of the world.

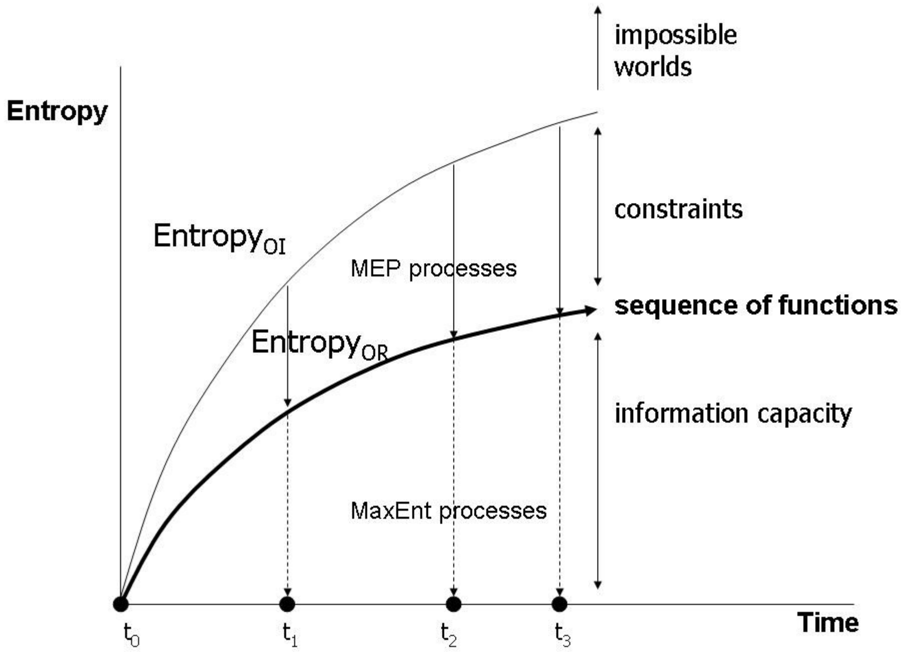


This shows that the emergence of life and of highly complex systems actually follows the Second Law, because it feeds on the increasing information capacity generated by actual entropy, but at the same time maximizes entropy because of the increasing gap to potential entropy. This corresponds to the idea that all systems ultimately are mechanisms for energy dissipation, and hence do not work against the Second Law.

We can give a more general version of this idea in terms of a general evolutionary law of increasing information content of realized systems. This law can be directly deduced from Weitzman's (1998) conception of combinational growth. We only need to assume that evolution proceeds in the way that existing potential states of systems are continuously combined into new possible states, such that, mathematically, the power set of all possible combinations grows when the underlying states space grows. From this follows the Weitzman proposition that all recombinant processes grow stronger than exponential growth processes, which implies that realized forms of life represent increasing information content because of the growing distance between the realized states and the possible states.

Fig. 7: The evolution of entropy

The purely qualitative diagram shows the two-sidedness of functions in evolutionary sequences that are projected onto physical time. Ultimately, functions dissipate energy and hence drive the growth of observer independent entropy. At the same time, they maximize observer relative entropy in the process of selection. The latter creates the information capacity from which new functions can emerge, thus driving further qualitative changes of the state space. Across the different points of time, $Entropy_{OI}$ *is commensurable, and* $Entropy_{OR}$ *is incommensurable, corresponding to Georgescu-Roegen's two conceptions of time.*



Following Layzer, Brooks and Wiley (1988) have proposed a simple qualitative diagram that I adapt here (fig. 7). The central message of this diagram is that the evolution of functions can be seen from two sides, namely $entropy_{OR}$ and $entropy_{OI}$. The evolution of functions maximizes $entropy_{OR}$ in the sense that on every step of functional evolution, the system of functions of observing systems will manifest the MaxEnt principle. Hence, we have different points in time onto which the state of $entropy_{OR}$ is projected. However, these different points are incommensurable in the Georgescu-Roegen sense because the underlying dynamics follows the Weitzman growth trajectory, i.e. manifests structural novelty in the combinations of states. Therefore, for each point of time the MaxEnt principle holds, but it is impossible to compare the different entropies qualitatively. This is exactly on what both Jaynes and Georgescu-Roegen could agree, though from a very different, even seemingly incompatible standpoint. In other words, and referring again to Ayres' distinction between D-information and S-information, the D-information in every point is contextualized with reference to the realized function, such that no unified measure exists, even though the fundamental physical magnitudes are the same.

However, the process also manifests continuous growth of $entropy_{OI}$, which is the reflection of the direct physical complementarity of the statistical mechanics and the thermodynamic view on entropy. As I have detailed in figure 4, this reflects the fact that via the working of functions, energy is dissipated corresponding to the maximum power principle, which, together with the dissipation into useless heat along the different levels of hierarchical systems with functions, ultimately results into MEP on the level of the total system. This approach is different from the Schrödinger view on evolution because all functions are seen as MEP gradients. The Schrödinger view that organism are states of order implicitly assumes a stable reference frame. However, in a moving reference frame the definition of order is endogenous. This is familiar from biology, where we can speak of entropy, in the sense of diversity, on different hierarchical levels, such as the diversity of individuals within a species, are the diversity of species in an ecosystem, and so forth. From the viewpoint of the individual diversity, the species characteristics may appear to be states of order, but they are themselves entropic phenomena on a higher level.

Hence, fig. 7 represents the essence of my reconciliation between Georgescu-Roegens fundamental philosophical position and modern maximum entropy approaches. Georgescu-Roegen's central concern was to distinguish two kinds of theories, arithmomorphic and qualitative (dialectic). The essence of this distinction lies in two different notions of time. In fig. 7 we have the mechanical time still on the x-axis, but there is a twofold projection. Whereas $entropy_{OI}$ corresponds to the arithmomorphic framework of statistical mechanics and thermodynamics, which was rejected by Georgescu-Roegen, it is precisely the modern approach to entropy developed by Jaynes that allows for recognizing the role of $Entropy_{OR}$. $Entropy_{OR}$ is a dialectic category that evolves endogenously with the qualitative evolution of the state space, hence the reference frame.

4 Conclusion: The relevance of the argument for economic analysis

I have shown that a fundamental feature of Georgescu-Roegen's natural philosophy of economics, namely the dualism of notions of time, can be interpreted in the context of modern maximum entropy approaches. The bridge is built on a generalization of Georgescu-Roegen's reference to subjectivity, which I interpret as observer relativity in the sense of Searle's, and in a second step of extension, as function relativity in a naturalistic approach, which is borrowed from teleosemantics. In this framework, I argue that the MaxEnt principle applies for the evolution of functions under natural selection, because it represents a principle of economics of information. MaxEnt implies the adaptation of functions to macro-level constraints, with no loss of information from imperfect knowledge about the microstates. In evolutionary hierarchical systems, this corresponds to the MEP principle, because natural selection, following Lotka's seminal conjecture, manifests the maximum power principle in terms of the functions. From this I deduce a general view on evolution that has been seminally developed by different scholars such as Brooks and Wiley, or Salthe, namely that evolution is the expression of the Second Law just because it manifests increasing complexity. The complexity of functions has the two sides of commensurable Entropy_{OI} and incommensurable Entropy_{OR}, which corresponds to Georgescu-Roegen's two notions of time.

My discussion is most general, so how does it relate with economics? I think that the argument presents the conceptual and philosophical framework for recent work by Ayres and collaborators (Ayres 2005, Ayres et al. 2005, 2008, Warr et al. 2008), in the same direction as e.g. Kümmel (1998), which shows that economic growth can be explained by the growth of useful work throughput, once the technological improvements in the transformation of exergy into work are taken into consideration. This is because exergy is the context-specific amount of free energy available in the system environment, and work is the useful energy expended in changing macrostates of systems. I interpret the effective substitution of the technological progress variable by the useful work variable in these models as a direct correspondence to the dualism between entropy_{OI} and entropy_{OR}.

That means, I conclude that economic growth directly reflects the Second Law in both senses. Firstly, economic growth is a sequence of functions which define a sequence of Entropy_{OR}. This is what reflects the increasing quantity of information that underlies the growth trajectory, and is the result of economic selection of functions, i.e. technologies, institutions etc. Secondly, economic growth manifests the continuous increase of energy throughput, hence the growth of Entropy_{OI}. This is reflected in the so-called rebounce effect, namely that in spite of ongoing technological innovation, the exergy throughput increases continuously (Ayres et al. 2003, 2005). This implies that we can interpret the increasing efficiency of the exergy/work relation as a movement towards steeper gradients in energetic dissipation, following the maximum power principle. In other words, increasing energetic efficiency of technology does not result into absolute savings of energy, but actually supports increasing use of energy, corrsponding to the ultimate MEPP.

This statement means, as Annila and Salthe (2009) have argued recently, that we can assume for economic growth a similar process as for the general case of the earth system. This is that all economic institutions, technologies etc. at least in the average will change in the direction of establishing gradients for energy dissipation that maximize entropy production. This, however, and contrary to Georgescu-Roegen, should not be directly interpreted in the sense of environmental issues, because the dissipative process can take many different forms, some environmentally degradating, others not, depending on the specific functions that underly the gradients. However, it does imply, and here corresponding to Lotka's conjecture, that economic evolution is always and necessarily accompanied by increasing energy throughputs and maximal entropy production.

This observation may be too obvious, but in fact it is not, given the implicit belief shared among many economists that the growth of knowledge itself may be a substitute for the use of energy. The other central consequence of our general framework is that one cannot treat information as an entropically irrelevant magnitude. This is evident to the physicist or ecological economist, but is rarely recognized in standard economics, where information is normally treated in mentalistic terms, as in the classical notion of exogenous technological change, or in the entire domain of game theory. The argument presented here implies that information always has two sides, the OI side and the OR side. Economics only focuses on the latter and ignores the former. The former has been recognized since Landauer (1961) as the energetic and entropic equivalents of Shannon information in computation as a physical process. In the context of economics, this implies that one cannot simply think of information as a generic resource that can substitute for energy, as Kümmel (1998) has suggested, in particular. Energy and information are the same, and the difference is only a structural one, relating to the functions. That means, intensifying information flows and information use will always follow the Second Law. Therefore, we can hypothesize that the growth of energy throughput is the other side of the coin of the growth of knowledge. In this sense, Georgescu-Roegen's warning voice is still with us.

References

Annila, Arto / Kuismanen, Esa (2009): Natural Hierarchy Emerges from Energy Dispersal, BioSystems 95: 227-233.

Annila, Arto / Salthe, Stanley N. (2010): Physical Foundations of Evolutionary Theory, forthcoming, Journal of Non-equilibrium Thermodynamics.

Ayres, Robert U. (1994): Information, Entropy, and Progress. A New Evolutionary Paradigm, New York: AIP Press.

Ayres, Robert U. (2005): Resources, Scarcity, Technology, and Growth, in: Simpson et al. (2005): 142-154.

Ayres, Robert U. / Warr, Benjamin (2003): Exergy, Power and Work in the US Economy in: Energy- The International Journal 28: 219-273

Ayres, Robert U. / Warr, Benjamin (2005):. Accounting for Growth: The Role of Physical Work, in: Structural Change and Economic Dynamics 16(2): 181-209.

Bateson, Gregory (1979): Mind and Nature. A Necessary Unity, London: Wildwood House.

Ben Jacob, Eshel (1998): Bacterial Wisdom, Gödel's Theorem and Creative Genomic Webs, Physica A: 57-76.

Ben Jacob, Eshel / Shapira, Yoash / Tauber, Alfred I (2006): Seeking the Foundations of Cognition in Bacteria: From Schrödinger's Negative Entropy to Latent Information, in: Physica A 359: 495-524.

Bradie, Michael, Harms, William, "Evolutionary Epistemology", *The Stanford Encyclopedia of Philosophy (Winter 2008 Edition)*, Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/win2008/entries/epistemology-evolutionary/>.

Chaisson, Eric J. (2001): Cosmic Evolution. The Rise of Complexity in Nature. Cambridge and London: Harvard University Press.

Chaisson, Eric J. (2005): Non-equilibrium Thermodynamics in an Energy-Rich Universe, in: Kleidon and Lorenz (2005): 21-31.

Dennett, Daniel C. (1995): Darwin's Dangerous Idea. Evolution and the Meanings of Life, New York: Simon & Schuster.

Dewar, Roderick C. (2005): Maximum-Entropy Production and Non-Equilibrium Statistical Mechanics, in: Kleidon and Lorenz (2005): 41-55.

Dewar, Roderick C. (2009): Maximum Entropy Production as an Inference Algorithm that Rranslates Physical Assumptions into Macroscopic Predictions: Don' Shoot the Messenger, Entropy 2009, 11: 931-944.

Dewar, Roderick, C. / Porté, Annabel (2008): Statistical Mechanics Unifies Different Ecological Patterns, Journal of Theoretical Biology 251: 389-403.

Dretske, Fred (1981/1999): Knowledge and the Flow of Information, Reprint, Stanford: CSLI Publications.

Frank, Steven A. (2009a): Natural Selection Maximizes Fisher Information, Journal of Evolutionary Biology 22: 231-244.

Frank, Steven A. (2009b): The Common Patterns in Nature, Journal of Evolutionary Biology 22: 1563-1585.

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

Gillett, Stephen L. (2006): Entropy and Its Misuse, I. Energy, free and otherwise, Ecological Economics 56: 58-70.

Jaynes, E.T. (1965): Gibbs vs. Boltzmann Entropies, American Journal of Physics, 33(5): 391-398.

Jaynes, E.T. (1982): Comments on "Natural Resources: The Laws of Their Scarcity" by N. Georgescu-Roegen, http://bayes.wustl.edu/etj/node1.html

Jaynes, E.T. (1998): The Second Law as Physical Fact and As Human Inference, http://bayes.wustl.edu/etj/articles/second.law.pdf

Kleidon, Axel (2009): Non-equilibrium Thermodynamics and Maximum Entropy Production in the Earth System: Applications and Implications, Naturwissenschaften 96: 653-677.

Kleidon, Axel (2010): Non-equilibrium Thermodynamics, Maximum Entropy Production and Earth-system evolution, Philosophical Transactions of the Royal Society A, 368: 181-196.

Kleidon, Axel and Ralph Lorenz (2005a): Entropy Production in Earth System Processes, in: Kleidon and Lorenz (2005b): 1-20.

Kleidon, Axel and Ralph Lorenz, eds. (2005b): Non-equilibrium Thermodynamics and the Production of Entropy. Life, Earth, and Beyond, Heidelberg et al.: Springer.

Kümmel, Reiner (1998): Energie und Kreativität. Stuttgart / Leipzig: Teubner.

Landauer, Rolf (1961/2000): Irreversibility and Heat Generation in the Computing Process (reprint), IBM Journal of Research and Development Vol. 44 (1/2): 261-269.

Layzer, David (1988): Growth of Order in the Universe, in: Weber et al. (1988): 23-40.

Lineweaver, Charles H. (2005): Cosmological and Biological Reproducibility: Limits on the Maximum Entropy Production Principle, in: Kleidon and Lorenz (2005): 67-77.

Lotka, Alfred (1922a): Contribution to the Energetics of Evolution, in: Proceedings of the National Academy of Sciences 8: 147-151.

Lotka, Alfred (1922b): Natural Selection as a Physical Principle, Proceedings of the National Academy of Sciences 8: 151-154.

Lozada, Gabriel A. (2006): Entropy, Free Energy, Work, and other Thermodynamic Variables in Economics, Ecological Economics 56: 71-78.

Macdonald, Graham / Papineau, David, eds. (2006b): Teleosemantics. New Philosophical Essays, Oxford / New York: Oxford University Press.

Millikan, Ruth (1989): Biosemantics, Journal of Philosophy 86: 281-297.

Neander, Karen, "Teleological Theories of Mental Content", *The Stanford Encyclopedia of Philosophy (Winter 2009 Edition)*, Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/win2009/entries/content-teleological/>.

Niven, Robert K. (2009): Jaynes' MaxEnt, Steady State Flow Systems and the Maximum Entropy Production Principle, arXiv:0908.0990v1

Niven, Ropert K. (2007): Combinatorial Information Theory: I. Philosophical Basis of Cross-Entropy and Entropy, arXiv:cond-mat/0512017v5

Odum, Howard T. (2007): Environment, Power, and Society for the Twenty-First Century. The Hierarchy of Energy, New York: Columbia University Press.

Paltridge, Garth W. (2009): A Story and a Recommendation about the Principle of Maximum Entropy Production, Entropy 2009, 11: 945-948.

Ruth, Matthias (2005): Insight from Thermodynamics for the Analysis of Economic Processes, in: Kleidon / Lorenz (2005): 243-254.

Salthe, Stanley N. (1993): Development and Evolution. Complexity and Change in Biology, Cambridge/London: MIT Press.

Salthe, Stanley N. (2007): The Natural Philosophy of Work, Entropy 9: 83-99.

Searle, John R. (1995): The Construction of Social Reality, New York: Free Press.

Searle, John R. (2004): Social Ontology: Some Basic Principles, http://socrates.berkeley.edu/~jsearle/articles.html

Vermeij, Geerat J. (2004): Nature: An Economic History, Princeton and Oxford: Princeton University Press.

Warr, Benjamin / Schandl, Heinz / Ayres, Robert U. (2008): Long Term Trends in Resource Exergy Consumption and Useful Work Supplies in the UK, 1900 to 2000, Ecological Economics 68: 126-140.

Weber, Bruce H., David J, Depew, and James D. Smith, eds. (1988): Entropy, Information, and Evolution. New Perspectives on Physical and Biological Evolution, Cambridge and London: MIT Press.

Weitzman, Martin L. (1998): Recombinant Growth, The Quarterly Journal of Economics CXIII(2): 331-360.

Whitfield, John (2005): Order Out of Chaos. Nature 436: 905-907.

Wolpert, David H. (2008): Physical Limits to Inference, arXiv:0708.1362v2.

Zeh, H. Dieter (2005): Entropie, Frankfurt: Fischer.

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