



Teleodynamics: Specifying the Dynamical Principles of Intrinsically End-Directed Processes

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TELEODYNAMICS: SPECIFYING THE DYNAMICAL PRINCIPLES OF INTRINSICALLY END-DIRECTED PROCESSES

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ABSTRACT

Seven parameters are described that distinguish three hierarchically nested system dynamics that are characteristic of partially-bounded open subsystems. These are used to characterize the transition from self-organized inorganic to self-regulated living systems which exhibit self-synthesis, self-reproduction, and self-reconstitution in response to damage. This analysis demonstrates that yoked self-organizing processes that generate each-others' boundary conditions can produce a form of co-dependent unity that exhibits these end-directed properties. A simple empirically testable molecular model system — an autogenic virus — is described for exploring these dynamical properties.

Keywords: organism, constraint, dissipative processes, self-organization, morphodynamics, autogenesis, MEPP, virus

NOMENCLATURE

- s: subsystem entropy
- Δs : entropy transfer rate (from sub- to super-system)
- ∇ : interface gradient (between sub- & super-system)
- $\int \phi$: total subsystem constraints
- $\int p$: combined dissipation path lengths
- L_{\min} : lower boundary condition
- L_{\max} : upper boundary condition

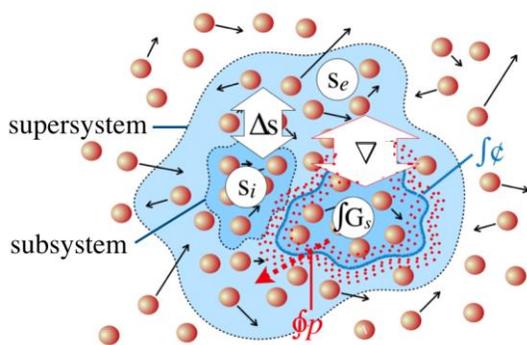


Figure 1: Selected subsystem-supersystem relations

1. INTRODUCTION

In previous works [1, 2] I have coined the term ‘teleodynamics’ to distinguish the distinctive modification of thermodynamic processes that characterize the intrinsic end-directed dynamics characteristic of life. The term is intended to recognize that the dynamical processes intrinsic to living organisms are structured with respect to contributing to the specific end of organism integrity and persistence (as well as reproduction). The point of making this distinction is also to signal that the global dynamics of organism is neither fully accounted for by near-equilibrium thermodynamic processes nor by far-from-equilibrium thermodynamic (aka self-organizing / dissipative) processes. Rather, the global co-dependence of the component material-energetic processes that constitutes an organism is characterized by state functions and path functions that are discontinuously different from those that define either of these nonliving dynamical conditions.

To frame this analysis I begin with the question “Does the theory of far-from-equilibrium self-organized dissipative processes provide a sufficient account of the energetic dynamics of living organisms?” Or, more succinctly, “Are organisms accurately modeled as self-organized dynamical systems?” In the following abstract I answer in the negative.

In many current efforts to characterize the thermodynamics of organism function it is assumed that they are to be understood as self-organized dissipative structures in Prigogine’s sense. [3, 4, 5] Self-organized processes are non-linear dynamical regularities that emerge within open dynamical systems that are persistently driven far-from-equilibrium while they are at the same time dissipating the effects of this perturbation. Under these conditions internal gradients tend to become increasingly asymmetric in ways that favor the formation of more orderly and more efficient dissipation pathways. The tendency to generate ordered structures is the inverse of the spontaneous order-reducing tendency characteristic of the 2nd Law of thermodynamics. This has suggested to many that since living processes also locally invert the 2nd Law tendency and produce stable ordered structures and dynamics, they too must be self-organized dissipative systems, describable by the same principles. But

there is an implicit problem with this assumption. Physical systems driven far-from-equilibrium tend to self-organize because this more rapidly and more efficiently counteracts the perturbing influence (e.g. energetic gradients) that induces these regularities to form. In this respect these regularities are intrinsically self-eliminating. In contrast, living processes are specifically organized so as to prevent self-damage and self-destruction. They are specifically structured in ways that efficiently preserve internal order by maintaining access to essential extrinsic supports. These extrinsic supportive conditions are formally analogous to the perturbing influences that drive self-organization, but in the context of organism function it would be odd to describe this as “perturbation.”

This leads to a paradox: Living systems depend on far-from-equilibrium dissipative processes to generate their orderly dynamics and structures, and yet they must prevent these same self-organizing processes from undermining the very conditions that they depend upon for their persistence.

To address this conundrum it is helpful to reflect on how living systems deviate from non-living far-from-equilibrium dissipative self-organized dynamics. To do this requires that the precision gained by focusing on isolated systems be sacrificed in order to gain the perspective offered by focusing on average ensemble properties of open systems that are in constant flux.

2. GENERALIZING THERMODYNAMICS FOR OPEN SYSTEMS

As a point of departure, consider the qualitative characterization of the traditional three laws of thermodynamics. Abstractly, we can categorize them as three state functions: a symmetry law (1st), a spontaneous symmetry-breaking law (2nd), and a boundary law (3rd), respectively. Together they have been deemed sufficient to characterize the material-energetic transformations that can take place within an isolated physical system. There have also been proposals for a fourth law that will not be considered here. [6] Instead, I suggest considering an expansion of the 3rd law so that it specifies both a lower and upper bound. Thus, for an isolated system in which there is no fundamental modification of the basic units of interaction (e.g. no nuclear transformation) there will be upper and lower limits beyond which no further asymmetric change can occur. With respect to isolated thermodynamic systems the lower bound is 0°K (as specified in the third law [7]) and the upper bound is the thermodynamic equilibrium condition; i.e. the maximum entropy state. In this way, both the lower and upper bounds identify state values beyond which (plus or minus) there can be no further net asymmetric change.

There is not space to review the many efforts to formulate a consistent set of principles sufficient to characterize the major modes of open system dynamics. The following overview will be presented in non-quantitative terms and focused on highlighting the differences between far-from-equilibrium dissipative self-organized processes and living dynamics.

One fundamental departure from the analysis of isolated thermodynamic systems is that the symmetry law must be abandoned when analyzing open systems. This has the consequence that precise finite solutions of state variables and parameters will not be possible. A precise delimitation of what characterizes the system under consideration is also not possible for an open system, and further limits the ability to precisely quantify the major parameters. This means that all analyses must be framed in terms of subsystem-supersystem relationships and often requires considering a subsystem that is open to distinct supersystems which themselves are partially or fully isolated from one another. Because of these complexities, the characterization of spontaneous symmetry-breaking will need to be partitioned into many subdimensions. In the following analysis the analogue to the Second Law will be partitioned into five different asymmetrical dispositions (see Figure 1).

In general terms I will characterize three levels of open system dynamics to help demonstrate the intermediate role of self-organized dissipative processes in mediating between near-equilibrium thermodynamics and living dynamics. I term them Homeodynamics, Morphodynamics, and Teleodynamics and below I distinguish their open system features with the above-listed (figure 1) parameters and dispositions.

Specifically, these three divisions are distinguished by inversion of the major symmetry-breaking dispositions. They are also asymmetrically dependent on one another. For example, morphodynamic relationships emerge from and depend on interactions between underlying homeodynamic processes, and teleodynamic processes emerge from and depend on interactions between underlying morphodynamic processes. This hierarchic nested dependency is defined with respect to distinctive inversions of the major state functions and path functions that were characteristic of the lower order dynamics. To summarize the logic of this nested dependency: the emergence of regularizing (morphodynamic) processes (often called self-organization) is due to the juxtaposition of inversely oriented equilibrium-approaching processes, and the emergence of regulated processes (associated with living and mental processes) is due to the juxtaposition of inversely directed self-organizing processes.

3. THREE DYNAMICAL MODES

3.1 Homeodynamics

In order to specifying these state and path functions for an open subsystem near equilibrium (here termed a homeodynamic subsystem) I list five symmetry-breaking descriptors and upper and lower bound conditions. They are listed in Table 1, along with brief descriptive explanations.

1. subsystem entropy	$S_t \leq S_{t+1}$
2. entropy transfer rate*	$\Delta S_t \geq \Delta S_{t+1}$
3. interface gradient	$\nabla_t \geq \nabla_{t+1}$
4. subsystem constraints	$\int \phi_t \geq \int \phi_{t+1}$
5. dissipation path lengths	$\oint p_t \approx \oint p_{t+1}$
6. lower boundary	$L_{\min} \ 0^\circ\text{K}$
7. upper boundary	$L_{\max} \ \int G_s = 0$

* = entropy production as in MEPP G = Gibbs free energy

Table 1: Homeodynamic parameters. Note that entropy transfer rate is related to the maximum entropy production principle (MEPP) and describes the rate of this change.

3.2 Morphodynamics

Partially bounded open dynamical subsystems that are driven persistently far from equilibrium tend to exhibit an inversion of many of the state functions that are characteristic of near-equilibrium unperturbed subsystems. For example, it is generally possible to identify an open subsystem region within which entropy tends to be driven down to a minimum value when it is subject to a persistent external perturbation driving it away from equilibrium. This is the case for vortices formed by the constant throughput of a fluid medium or for Rayleigh-Bénard convection within a fluid layer heated from below and giving off heat from its surface. In prior work [1, 2] I have used the term ‘morphodynamic’ to distinguish those dissipative self-organized subsystems that converge toward a stable low-entropy regularity.

A subsystem becomes morphodynamic when it is subject to a perturbing influence that decreases its entropy at a rate that exceeds its ability to spontaneously dissipate this disturbance. Continual perturbation increases gradients to the point that this becomes a source of work which organizes dynamical flows to reduce total dissipation-path length by increasing dynamical constraints to the point that the dissipation rate comes to equal and compensate for the perturbation rate thereby eliminating the capacity to do further organizing work.

1. subsystem entropy	$S_t \geq S_{t+1}$
2. entropy transfer rate*	$\Delta S_t \leq \Delta S_{t+1}$
3. interface gradient	$\nabla_t \leq \nabla_{t+1}$
4. subsystem constraints	$\int \phi_t \leq \int \phi_{t+1}$
5. dissipation path lengths	$\oint p_t \geq \oint p_{t+1}$
6. lower boundary	$L_{\min} \ \text{homeo}$
7. upper boundary	$L_{\max} \ \Delta S_i = \Delta S_e$

* = entropy production as in MEPP

Table 2: Morphodynamic parameters. (Red entries indicate changes with respect to homeodynamic relations)

Note that the lower boundary where these properties no longer hold is to degrade to homeodynamics and the upper

boundary is reached when perturbing (input) entropy rate of change equals the dissipation (output) rate of change.

3.3 Teleodynamics

Living subsystems do not merely counter the second law of thermodynamics internally, they also deviate from the pattern of state and path functions that are characteristic of self-organizing (morphodynamics) processes. This is because they result from the coupling of opposed morphodynamic processes that generate each other’s supportive and limiting boundary conditions. The result is the creation of whole system level constraints that stabilize the runaway tendencies of these component far-from-equilibrium dissipative processes. These holistic subsystem constraints are thereby preserved and capable of being replicated in new substrates because they are not identical to the constraints of any of the component morphodynamic processes; they are systemic and distributed as relational constraints. For this reason, and unlike homeodynamic and morphodynamic subsystems whose distinction from their super system context is in effect arbitrary and an analytic heuristic, the distinction between a teleodynamic subsystem with respect to its super system is internally determined. It is not merely an analytic decision. So although teleodynamic subsystems are open systems that require exchange of energy and matter with their super system context, they are at the same time self-bounded. This is of course the paradoxical nature of organism self. In addition, whereas the lower bound a teleodynamic system is to degrade to unregulated morphodynamic runaway and death, it is not clear that there is an upper bound. This is because holistic constraint preservation enables the possibility of constraint accretion and complexification and with this the increase and complication of dissipation path lengths that characterizes the ratchet-like effects of biological evolution.

1. subsystem entropy	$S_t \approx S_{t+1}$
2. entropy transfer rate*	$\Delta S_t \approx \Delta S_{t+1}$
3. interface gradient	$\nabla_t \approx \nabla_{t+1}$
4. subsystem constraints	$\int \phi_t \approx \int \phi_{t+1}$
5. dissipation path lengths	$\oint p_t \leq \oint p_{t+1}$
6. lower boundary	$L_{\min} \ \text{morpho}$
7. upper boundary	$L_{\max} \gg \infty?$

* = entropy production as in MEPP

Table 3: Teleodynamic parameters. (Red entries indicate divergence from both homeodynamic and morphodynamic properties).

To provide an empirically testable model system to verify whether or not these properties exemplified by living organisms can indeed be produced by the coupling of complementary morphodynamic processes consider the possibility of a hypothetical *autogenic virus* (see figures 2 and 3). All known viruses are parasitic and commander the molecular machinery

of other living cells to replicate their nucleic acid genetics and synthesize the molecules that form their capsid containment. This is because of the complexity of the molecular machinery needed to replicate nucleic acids and to transcribe nucleotide sequences to produce their protein capsid molecules. But the simplicity of viral structure suggests a way that viral reproduction could be autonomously accomplished. This is because viral capsids self-assemble due to the symmetries of component capsid proteins and because there are other means for molecular replication than via nucleic acid templates.

Elsewhere [1, 2] I have described replacing the nucleic acid contents of a viral capsid with an autocatalytic set; a set of two or more catalysts that reciprocally catalyze the production of each other. If in such a catalytic circle one of the side products produced is a capsid forming molecule capsid formation will tend to occur most rapidly and effectively where there is rapid reciprocal catalysis, thereby tending to enclose the very catalysts that tend to replicate themselves and their containment (see figure 2). So that if containment is breached in an environment with appropriate catalytic substrates the entire molecular complex will tend to reconstitute or replicate itself. Each morphodynamic process in isolation results in a runaway and self-terminating process, but coupled each generates the permissive and stabilizing boundary condition for the other. The result is a process that achieves the teleodynamic properties described above and characteristic of more complex living processes.

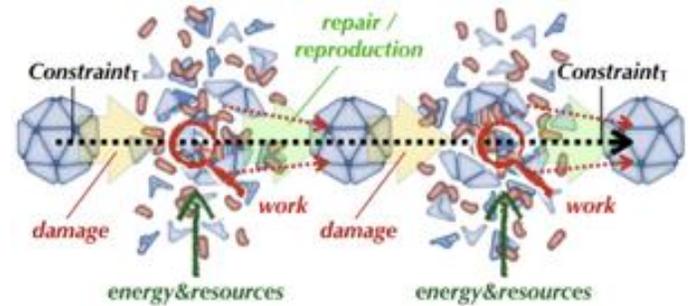


Figure 3: Replication-repair cycle of an autogenic virus maintains continuity of the co-dependent system of constraints across “generations.” These teleodynamic constraints both channel work and record themselves in new molecular substrates with each cycle.

4. CONCLUSION

This demonstrates how intrinsically end-directed self-bounded dynamically open systems such as are living organisms (including viruses) can emerge from co-dependent dynamical relationships between coupled far-from equilibrium self-organizing processes that reciprocally preserve each-other’s supportive boundary conditions. And the autogenic virus model system additionally demonstrates that the intrinsic reciprocity of these morphodynamically generated boundary constraints is functionally equivalent to genetic information, despite being distributed holistically in system organization.

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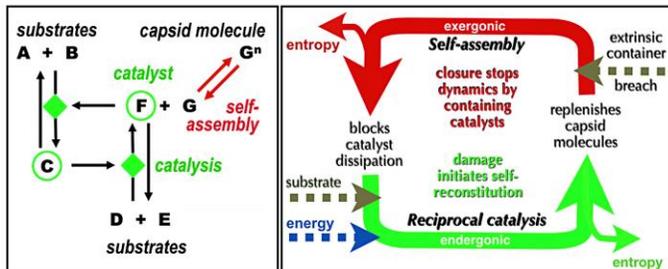


Figure 2: Chemical reaction diagrams of a simple autogenic virus. LEFT: Generic reaction diagram for a simple autogenic virus. Letters = molecules, green diamonds = catalyzed reactions, black arrows = chemical reactions, red arrows = self-assembling molecular relations. RIGHT: Autogenic work cycle diagram depicting reciprocal boundary conditions produced by the coupling of two morphodynamic processes: reciprocal catalysis (endergonic) and self-assembling molecular relations (exergonic).