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Convergence and *divergence* in the production of energy transformation hierarchies

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ABSTRACT

Divergence is an undertheorized process in energy transformation hierarchies. Energy transformation hierarchies are generally described as a stepwise convergence of energy and materials, with characteristic properties of increasing storage size, turnover time, and spatial scale, but they may also include the action of divergence that feeds other scales or systems of convergence. These patterns are particularly obvious when systems theory is applied to understanding economic “commodity chains” in the global economy. Divergence is also a fundamental process in the production of culture in “information cycles”. After a conversation, for example, the divergence of people with new information into the world, where that information is tested and possibly selected again, is a fundamental step in the wide sharing and upgrading of cultural information. A general conclusion is that divergence makes outputs available to coupled systems or scales that differ in space, function, or time.

1. Introduction

The energy transformation hierarchy is the name given by Odum to his proposed fifth law of thermodynamics (1996). It rests on his fourth law, the maximum empower principle. In the fourth law, Odum contended that systems self-organize to capture and use available energy, to maximize energy intake, energy transformation, and those uses that reinforce production and efficiency. By this process, energy transformations may come to be linked in a hierarchy. Energy transformation hierarchies have regular form and characteristics (Fig. 1). Considering Fig. 1b, many events of shorter duration on the left contribute to fewer and longer events as one moves to the right. In energy transformation hierarchies, as energy is converged (moving to the right) ideally there are larger and fewer objects, which have longer turnover times, larger spatial scale, higher search/exploration ability, higher maintenance cost, can take more varied inputs and/or from varied sources, and have larger feedback effects (Odum, 1996: 24).

By this account and in Fig. 1, the principle feature of energy transformation hierarchies is the *convergence* of energy in work processes. In work processes, energy and materials come together in the production of a product. The product may be an animal in a forest or a widget in a factory, and inputs to the animal include the energy embodied in its prey or plant food sources, while inputs to the widget include materials, electricity, knowledge, and human labor. The animal incorporates a portion of its inputs to the maintenance and growth of its bodily form, but most of the embodied energy is dissipated as heat. The widget is nearly the same, most of the energy in electricity, knowledge, and labor is dissipated with a remainder of embodied energy in the widget itself, and some waste materials. Thus, in energy transformation hierarchies a majority of energy is dissipated at each transformation as material and energy is converged in processes. In ecosystems and in human economies, each process is but one in a converging chain of processes.

This pattern of convergence is of great interest and import as the ideal of self-organization and hierarchy. Yet, as we know from ecosystems, ‘energy flows while materials cycle’. In a food chain or industry, there is always a waste stream. In ecosystems, material waste in decaying organic matter will be eventually dispersed to soil background concentrations where it may be again captured and converged into the bodies of plants. This dispersal is the ‘recycle’ flow in an aggregated diagram like Fig. 2. However, not all waste goes to this recycle flow. In both ecosystems and industry, waste may be captured and reinserted into the convergence process. This stream is not dispersal but is here distinguished as ‘divergence’.

Divergence is an undertheorized process in the production of energy transformation hierarchies. The death of any organism, or even the excretion of waste, may only partially lead to the dispersal of nutrients. Scavengers, like dung beetles, detritivores, or coprovores, all take up some portions of decaying organic matter into their bodies, where they contribute to *renewed convergence* and upgrading in trophic chains. These obvious processes are

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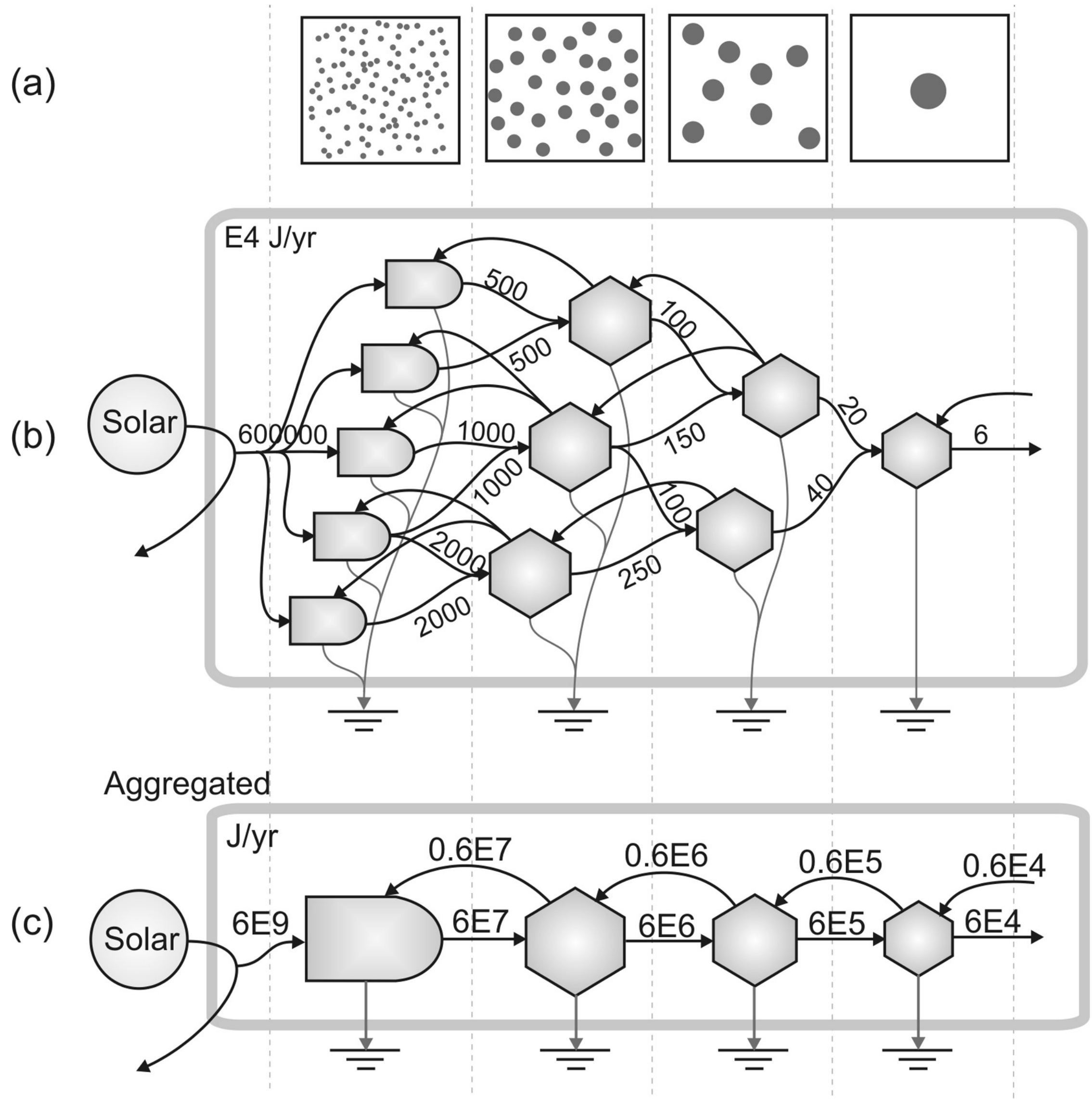

Fig. 1. Energy transformation hierarchy, after Odum (1996). "Flows of energy develop hierarchical webs in which inflowing energies interact and are transformed by work processes into energy forms of higher quality that feedback amplifier actions, helping to maximize the power of the system" (Odum, 1983: 251). See text for further description. Notice that in these aggregated diagrams there is no 'recycle', as in Fig. 2. Feedback and recycle are fundamentally different, though both flow to the left in a systems diagram. Feedback is an autocatalytic flow that amplifies energy capture at the scale below its source (four 'scales' shown here). Recycle, as in Fig. 2, is the dispersal of materials from a stored form, as in the scattering of organic nutrients following the death of an organism.

well-known but often ignored in the creation of simplified systems diagrams, which are intended to represent the characteristic steps of aggregate production, consumption, and convergence of energy and materials in food webs or chains (Fig. 2).

Divergence can also be found in landscape and geologic processes (Fig. 3). In a watershed landscape, rivers converge water into larger rivers as they move downhill. As gradients become smaller, rivers may meander. Larger rivers were the sites of great cities in the past. Finally as they approach the coastline, rivers diverge and river water spreads, either as a distributary or diverging into estuaries (Fig. 3a).

Within continents, mountains are the centers of convergence of plate movements (Fig. 3b). The higher the mountains, the faster their erosion. Typically, the mountains are pulsed up and erode for a time before energies accumulate for another pulse. Mountain formation is convergence, but erosion is the divergence of rock particles into surrounding landscapes, assisted by water and wind (Fig. 3c).

In both of these examples, typical emphasis is on convergence in energy hierarchies. But we should consider the divergent processes. What these examples share is the movement of energy and materials into distinctively different systems. Nutrients and the kinetic energy of river watersheds 'jump' systems as they diverge into deltas and estuaries. A new convergence will begin that makes use of the diverged watershed products in a coastal food chain. In a similar manner, the geologic processes that produce mountains also produce an output that jumps systems, here again to the ecosystem scale, this time of a terrestrial food chain, where a new convergence begins using the diverged nutrient products of the geologic system.

2. Divergence in human economies

The aim of this paper is to apply systems thinking to the study of production in economies, households, and culture. The importance of divergence becomes particularly salient when systems think-