Parallel Cycles for the Emergy Evaluation of Information in Manufacturing, Culture, and Life

Thomas Abel

Tzu Chi University, No. 67, Jieren St., Hualien, Taiwan

*Corresponding author's email: tabel@gms.tcu.edu.tw

Received: 6 September 2022/ Accepted: 6 March 2024

Abstract. For environmental accounting, the incorporation of human cultural information is challenging. In 1987, Howard T. Odum published an emergy analysis of highways in Texas. The highways were conceived as typical environmental-industrial products; however, his analysis incorporated the unusual feature of evaluation of the *information* required. Information for highway use was in the production of highway maps, which was his principal object of information study. However, in addition, he also evaluated the information for the control of highway production in specification documents. His study addressed the creation of both information forms, and the evaluation of that information with emergy. In this paper, that analysis is re-examined considering a theoretical and methodological advancement in the study of material production with information control. That advancement is the modelling of two distinct forms of information that are required for any manufactured or information product. That modelling makes use of the 'information cycle', a systems design that assures the maintenance and perpetuation of information against Second Law depreciation of information carriers. The two information forms are labeled here the *object information* and the *expression information*. The *object information* is the template for the final product (the 'design specs' for a widget, the script of a play, or the DNA of an organism). The *expression information* in cultural production is the operating procedures, standards, and conventions for setting, venue, or factory that enable the object, while in life, the *expression information* is the programmed behavior of the organisms and organs of reproduction. Based on the 'information cycle', this paper uses Odum's highways study to demonstrate a 'parallel cycles' model for the perpetuation of the two forms of information.

Keywords: information, culture, emergy, information cycle, cultural transmission, environmental accounting

1. Introduction

In the systems theorizing of Howard T. Odum, information is of great value to systems (Odum, 1971, 1987, 1988, 1996, 1999a, 2007; Odum & Odum, 1976). Self-organized systems that incorporate information preserve a record of their formation and function that feeds-back control for persistence and reproduction (Odum, 2007, p. 88). This valuable information is preserved in 'information cycles' (Odum, 1996, p. 223) that select successful designs, extract their information, make copies, and disperse those copies into the world. The thorough incorporation of information is essential to achieving a successful environmental accounting of human-environmental systems.

For environmental accounting, the incorporation of information is challenging. This paper addresses a conceptual issue with broad application to any form of environmental accounting and, more generally, to theorizing about culture. Demonstration will be conducted with the method of *emergy* evaluation (Odum, 1996). It will be argued that two information forms are required to produce both life and culture. They are labeled here the *object information* and the *expression information*. When systems scientists attempt to account for information, they frequently overlook expression information. The *object information* is the template for an organism (in DNA) or cultural object (the 'specs' of a manufactured object, the script of a play, the score of a symphony, etc). The *expression information* in cultural production is the operating procedures, standards, and conventions for setting, venue, or factory that enable the object, while in life, the *expression information* is the programmed behavior of the organisms and organs of reproduction.

Odum's 'information cycle' model provides an understanding of the production, maintenance, and evolution of information for any system that includes information. Emergy researchers have probed the model, exploring different applications (Abel, 2013, 2014, 2016, 2017, 2023a; Brown, 2015; Campbell & Lu, 2014; Ulgiati & Brown, 2014). This paper proposes another refinement, a 'parallel cycles' model for the perpetuation of the two forms of information. It includes a demonstration of the emergy evaluation of the contribution of *object* and *expression information*. It is held that both forms are essential to any system that requires information. As such, both forms must be preserved in separate but linked information cycles or, in my terminology, 'parallel cycles'. A first emergy 'parallel cycles' demonstration has been recently published (Abel, 2024). A much elaborated explanation of theoretical principles for the 'parallel cycles' model used in that paper is found in this current paper.[1]

Consider some examples of parallel cycles. The information in the performance of an opera is the essence of the sight and sound that reaches you. But when the singers and musicians

[1] As sometimes happens in publishing, papers cross each other in time. This current paper was written before Abel (2024). As stated, the purpose of this paper is to thoroughly explore the theoretical justification for the parallel cycles model. The second purpose is to argue that in the Texas Highway study, Odum demonstrated the value of a parallel cycles model, though without naming it as such.

reproduce an opera, they rely on the physical opera house and its skilled operators. They rely on the knowledge and management of the opera director. And finally, they rely on the standards and conventions of professional opera. This information is not the score, and it is not the sight and sound of the performance, it is 'expression information'.

Or think of the manufacturing of a widget. The information for widget production is in the 'design specs' for the object and is embodied in the object once produced. But the equally valuable information for production is in the design of the factory, logistics, worker skills, and distribution. Often overlooked when considering the information required for a manufactured object, this 'expression information' is no less essential.

Or think of the information in a news 'story': A car crashed, people hurt. But the information for building and operating a newsroom, for how to make that news story, and indeed, for determining what things belong in the news, is a different set of information, and must have its own 'information cycle'.

Or last, consider the production of academic research in a journal paper or book, which is the topic of analysis in Abel (2024). The information objects are academic paper or book. But of equal value is the information needed to operate a research center or university department, and the information required to run a publishing house.

This paper will present a conceptual and quantitative demonstration of the distinction between *object* and *expression information*, and how they are joined in a *parallel cycles* model. The paper will begin with an introduction to three systems models – the information cycle model, the structural life cycles model, and the parallel cycles model – which will be followed by an empirical application of the parallel cycles model. That application is based on a prior study by Odum, a study of Texas highways (Odum, 1987, pp. 47, 80-81), which intends to demonstrate the affinity between his theorizing and the parallel cycles model. It will utilize emergy analysis (Odum, 1996), the form of environmental accounting pioneered by Odum.

1.1 The Information Cycle

After many years of writing about information (Odum, 1971, 1977; 1983, pp. 302-322; 1987, 1988, 1989, 1995; Odum & Odum, 1976), H.T. Odum produced in 1996 a simple model of information production and maintenance that incorporated his fundamental concern with open systems of energy self-organization. He called the model the 'information cycle' (sometimes 'information circle').

Because information has to be carried by structures, it is lost when the carriers disperse (second energy law). Therefore, emergy is required to maintain information. Information is maintained by copies made faster than they are lost or become nonfunctional. But copying from one original is not enough because errors develop (second law), and copying doesn't make corrections. So in the long run, maintaining information requires a population operating an information copy and selection circle (i.e., an information cycle) (Odum, 2007, p. 88).

With the 'information cycle', HT Odum proposed a general model of information and its reproduction, maintenance, and use (Figure 1). Information is never produced once and extended abstractly through time. It is perpetually cycled and tested, with errors eliminated and adjustments incorporated.

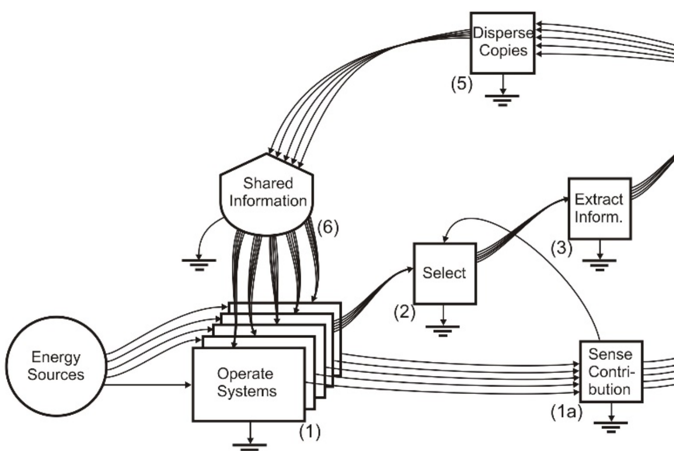

Figure 1. The Information Cycle. An information cycle as diagrammed by Odum (1996, p. 223), with step numbers added (reproduced with permission of John Wiley & Sons, Inc.). This general model applies to the production and maintenance of all forms of information. The step numbers, labeled functions, and diagramming conventions are nearly identical to those in Figure 2, below, as will be seen. For the 'Operate Systems' object, the multiple process boxes are intended by Odum to represent a "set of parallel operations, each organized with a copy of the structural and operational information (Odum, 2007, p. 228)."

Walking through the information cycle for the case of a population of sexually reproducing organisms, we begin with an ecosystem (Step 1 in Figure 1), from which mating pairs are *selected* (2) by that system context (1a) for reproduction. DNA information from each pair is *extracted* into new configurations (3). Those designs are used to make *copies* of organisms (4), which are then *dispersed* (5) into the larger *world* (1), where they live their lives. Any of the offspring may or may not be later *selected* (1a and 2) to transmit their DNA to the future. A similar walkthrough can be performed for any of the scales of cultural information, see Abel (2014). Readers should keep in mind this simple model of steps 1,1a,2,3,4,5, for they will re-appear in each of the alternative parallel cycles models included below.

1.2. Structural Life Cycles

Odum diagrammed the information cycle with slight variations for several publications (Odum, 1996, p. 223; 1999a, p. 239; 2007, pp. 89,227). The diagram Figure 1 was Odum's original 'information cycle', and I have re-used it in many publications (Abel, 2014, 2015, 2016, 2017, 2019, 2023a). For *Environment, Power and Society for the Twenty-First Century*, Odum drew three information cycles (Odum, 2007, pp. 89, 227, 229). In the third diagram, a fundamental difference was incorporated that originated in a workshop paper on building construction (Odum, 1999b, p. 30). In that paper, Odum described the processes that lead to the construction, maintenance, and eventual depreciation of a 'structure', which was in that case a building, but which could obviously be applied to the construction of any human cultural product. In *EPS* (2007, p. 229), Odum re-used that component of the model in a dramatically different reconceptualization of the 'information cycle' (Figure 2). What makes it different is the incorporation of the cultural object that depends on information for its production. In prior models, information moved through the cycle – extracted, copied, dispersed. But in what form is it dispersed? From what object is it extracted? And how is it 'carried' within the cycle? When applied to life, those objects are understood. But when applied to cultural objects, it is of great value to address them explicitly, as will be shown.

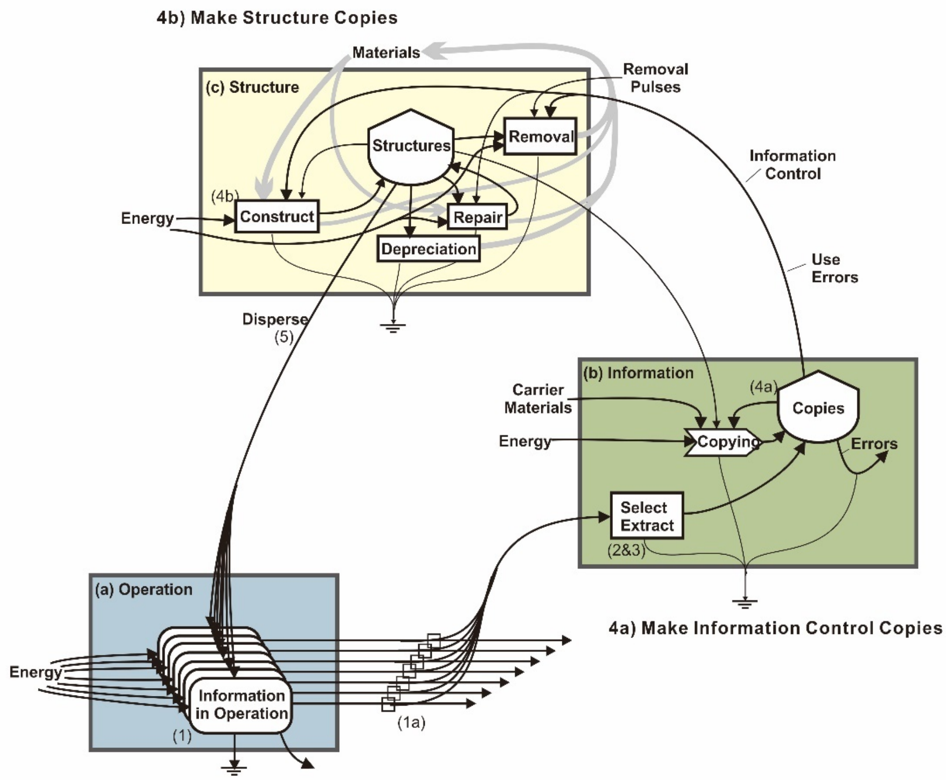

Figure 2. The Information Cycle (Structural Life Cycles version). This is the 'Structural Life Cycles' version (Odum, 2007, p. 229) (used with permission) of Odum's original 'Information Cycle' (Figure 1). This diagram is redrawn for this publication, to distinguish subprocesses with color, and to add step numbers. Again, recall that the step numbering scheme (1,1a,2,3,4,5) is intended to be equivalent to the numbering in Figure 1.

Systems diagrams typically are drawn with a single boundary. Figure 2, in fact, combines three distinct systems (or here referred to as subsystems of the total Structural Life Cycles system), and that fact is accentuated with the use of color. Information cycle step numbers have been added and coincide closely with the step numbers in Figure 1. The 'Make Copies', Step 4 is here divided into two phases. First, 4a is labeled 'Make Information Control Copies', while second, 4b is labeled 'Make Structure Copies'. Information Control copies are the templates for the design. Structure Copies are the final communication objects, or widgets, or eggs/offspring that are produced in the 'Construct' process box of subprocess *(c) Structure*, and then Dispersed (5).

Figure 2 depicts the *physicality* of living or manufactured objects, not only the *information* required for their production. The prominent storage 'Structures' can represent many things, Odum's examples include cars, microbes, or landscapes (2007, p. 227), people and oak trees

(2007, p. 230). Odum labels this diagram 'structural life cycles' to emphasize that information exists because of the *function* it performs, for the guidance of the production and maintenance of these *structures*. With this quotation, consider the subprocess *(c) Structure* in Figure 2.

The life cycle of structure includes construction, depreciation, repair, and removal for replacement with new construction. A self-maintaining population pumps in flows of materials and potential energy; combines materials to form parts; throws old parts out, sometimes reusing them as materials; rearranges new parts and disarranged situations; and transforms fuel energies into structural storages of potential energy with the form needed to operate the system (Odum, 2007, p. 228).

'Structures', therefore, may be living organisms or manufactured objects. It is my position that 'structures' can also be information objects, e.g., the performance of a play or symphony, an academic book, the teaching of a class, each of which also requires information for its production.

Odum intended the information cycle to reach beyond biology, to be applied to the evolution of information of both culture and life (Odum, 1996, p. 223ff). In prior publications, I have shown its use for cultural information 'objects', such as songs, news stories, semester courses, software programs, books, money concentrations, performances, social media 'posts', laws, patents, etc (Abel, 2014, 2015, 2016, 2017, 2024). It is now my view that the structural lifecycles model is a better model, because it addresses both the information in the song or story, while also the information required to produce the song or story. The same can be said for manufactured objects, which are both designed with information and produced in an information-guided process. But these two cultural applications have revealed an important issue that is opaque when organisms are the object of the cycle, which was not addressed by Odum when he originally proposed the model – the necessity of a second, parallel cycle, the subject of this paper.

1.3. Parallel Cycles

If information must always be preserved in information cycles of select, extract, copy, and disperse, then both the song or story and the information required to produce the song or story require separate information cycles. For manufactured objects, both the information of object design and the information for enabling the manufacturing of the object require separate information cycles. That is the position of this paper.

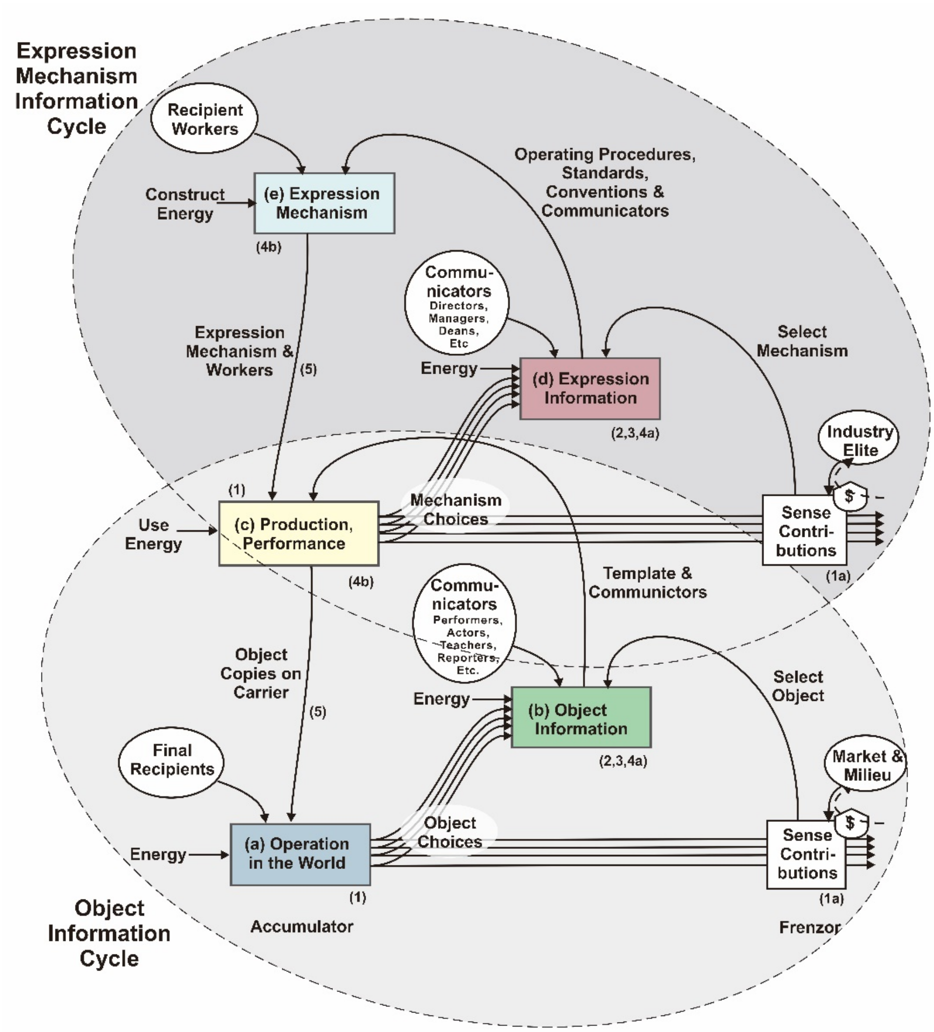

Figure 3. Parallel Cycles, Simplified Form. Once again, the reader should recognize the original information cycle step numbers (1,1a,2,3,4,5). With the parallel cycles model there are two distinct, but linked, information cycle models. Therefore, the sequence repeats in both lower and upper cycles. See the text for more explanation.

Refer therefore to Figure 3, which depicts the parallel cycles model in simple form. A detailed parallel cycles model with the resolution of Figure 2 is provided in Appendix B for readers who might wish to make a direct comparison. But my intention with Figure 3 was to design a diagram in simple enough but sufficient form that it could be applied to the study for this paper, also to the Abel (2023b) study, and ultimately one that could be applied by other researchers who are attempting to produce their own parallel cycles emergy analysis.

With the parallel cycles model there are two distinct, but linked, information cycle models. As marked in Figure 3, the Object Information Cycle is below, and the Expression Mechanism Information Cycle is above. With two cycles, the step sequence (1,1a,2,3,4,5) repeats in both lower and upper cycles. Note that subsystem (c) *Production, Performance*, which is shared by both models, is given two step numbers (4b and 1). The 4b step refers to the Object Information Cycle below, while the step number 1 refers to the upper information cycle for the Expression Mechanism. Notice also that steps 2 (Select), 3 (Extract), and 4a (Make Copies) in both the upper and lower cycles, are grouped together under the subsystem boxes (b) *Object Information* and (d) *Expression Information*. Placing these steps together under one process box was intended to simplify the parallel model, while maintaining its functionality. These steps deal specifically with the duplication of information, and can therefore be expediently joined together.

We will now address the model more methodically by following the step sequences (1,1a,2,3,4,5) in the top and bottom. In Figure 3, the bottom 'Object Information Cycle', is essentially identical in function to Figure 2. The value of information in the *world* (step 1) (an opera, novel, FB post, etc) is *sensed* (1a) by the larger scale of market or social milieu. Among the many copies, a well-functioning instance is *selected* (2) and its essence or gist or 'template' is *extracted* (3) for making *copies* (4a). Copies are made by the Communicators (the performers, other authors, or FB users, etc) and together with the template they move to the *production* of many *copies* (4b) of the performance, new book, new post, etc. with the aid of 'expression mechanisms' (opera houses, publishing houses, internet, etc) (flowing down from subsystem (e) *Expression Mechanisms*). Those information copies are then *dispersed* (5) to the final recipients back in the *world* (1).

The top half of Figure 3 is again the 'Expression Mechanism Information Cycle'. With a different cycle time, sometimes slower, sometimes faster, a well-functioning 'mechanism' for the production of information objects (step 1, step numbers now refer to the cycle in the upper half of the diagram) is *sensed* (1a) and *selected* (2) and its design is *extracted* (3). With the help of a different set of 'Communicators' (directors, managers, engineers, etc), the *copies* of procedures, conventions, standards, specifications, etc) move on to a different set of recipients (the support workers) for the production of the 'expression mechanisms' (4b) (again, the opera houses, publishing houses, internet, etc). These mechanisms are then *dispersed* (5), figuratively, back to the many sites of the production of the new object/performance, the one shared subsystem of both cycles, (c) *Production*, *Performances*. (The term ‘performance’ was chosen to be generic. Certainly, it applies to the production of a play, or lecture, or song, or TV show, but metaphorically the production of research, a computer program, a loan, a law, or even a widget are each a kind of performance. The term is intended to be a reasonable compromise.)

2. Study Area: Highway System of Texas

Is there any evidence in Odum’s information research that he shared my concern with the parallel information required for the *expression* of information, i.e., the *expression information* and the information cycle necessary for its evolution and maintenance? For Abel (2023b), I endeavored to review every emergy evaluation of information that was published by Odum. I found no case study that included expression information until I encountered the Texas Highway analysis (Odum, 1987, pp. 47, 80-81). As other information scientists, Odum was drawn to information objects, e.g., DNA, library books, TV news, and others. The Texas Highway study, however, stood out for its unique design. The information component of that study was another typical end-user information product, *highway maps*. However, after careful examination, a second informational component was discovered, the specification books required to build the highway. It is the highway from which ‘map’ information is extracted. But the parallel form of information required for the creation of the highway itself, was the specification documents. In that sense, the highway is the context (expression mechanism) for the production of the information object (maps). The fitting of the Texas Highway study to my parallel cycles model is quite good, and thus provides explanation for the unusual design.

In 1987, when he received the *Crafoord Prize* (Odum, 1987), Odum gave a long lecture in which he reviewed his accomplishments up to that point in time. One section of that lecture was addressed to information and complexity (Odum, 1987, pp. 43-52). One part of that was an evaluation of the hierarchy of information in the Texas Highway System (Odum, 1987, pp. 47, 80-81). Odum credits the ‘data’ for the study to a student project (Lyu, 1986), which implies that the diagrams, figures and analysis are his work. As the empirical component of this paper, the Texas Highways study will now be reanalyzed as a case study of the Parallel Cycles model. Odum did not characterize his study in the terms that I am using, of course, that is my contribution, but the ease by which this study fits the parallel cycles model suggests to me that

Odum had reached a similar understanding. It was that congruity that attracted me to the study as a demonstration.

Emergy analyses typically begin with a 'systems diagram', which depicts the system in terms of energy 'sources', 'interactions', 'storages', 'flows', and other energy processes of interest. This diagram of Texas Highways (Odum, 1996, p. 177) (Figure 4) was not included with the analysis in the *Crafoord Prize Lectures* that is being explored for this paper, and may have been drawn some years later. But it does apparently refer to the same research, and it therefore gives the reader a systems overview of the research project. The aggregation of sources and input flows does not match precisely with the quantitative study reported in the *Crafoord Prize*. It is included here to allow the reader to visualize the research setting, and to supply a few more labels that were omitted in the *Crafoord Prize*.

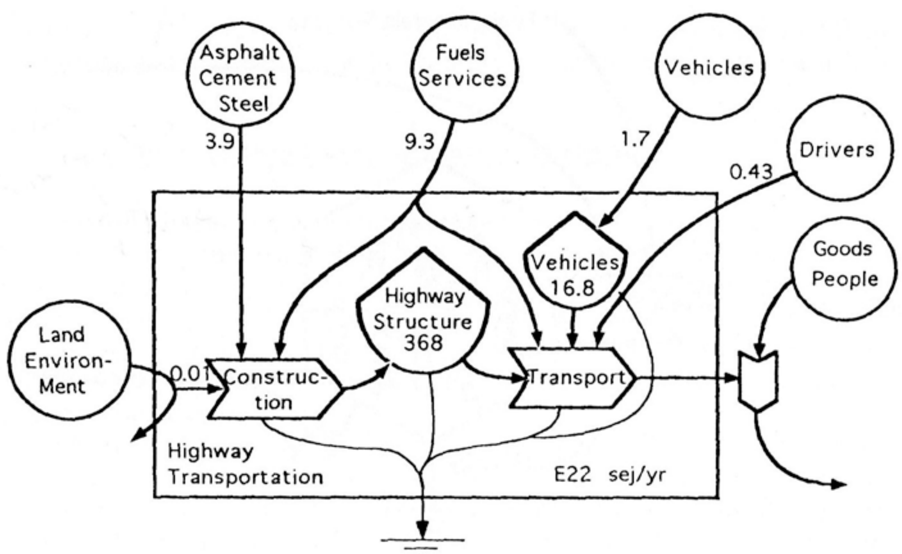

Figure 4. Summary of Emergy Evaluation of the Highway System of Texas (Odum, 1996, p. 177) (reproduced with permission of John Wiley & Sons, Inc.). Notice that no information production is shown within the window. Information will be depicted in the next diagram and in the Parallel Cycles diagram below. In 1996, Odum again attributes the 'data' to a student project (Lyu, 1986).

For example, in the diagram, the interaction symbol labeled 'Construction' is referred to in the *Crafoord Lectures* as the 'Highway Construction and Maintenance Emergy'. That aggregated input emergy is given a verbal description as the product of Asphalt, Cement, Steel, Fuels, and Labor (Services) (1987, p. 80) and each is visible as a source in Figure 4. The second major aggregated input in the *Lectures* is referred to as 'Highway Use Emergy', however Odum did not itemize the inputs for this second source. From the diagram, it is reasonable to locate 'Highway Use Emergy' at the other interaction symbol labeled 'Transport', which is therefore the product of Fuels, Services, Vehicles, Drivers, and the Highway Structure storage. Again, each of those flows are visible in Figure 4. Because some emergy flows on the diagram are not given values (the flow from Highway structure) and others cannot be divided (Fuels and Services), however, the diagram does not provide an independent means to calculate the two major aggregated emergy inputs in the *Crafoord Prize* analysis below. Notice also that the information products are not included in the diagram. To address that, I have made a complementary diagram that highlights the information products and the aggregated emergy sources (Figure 5).

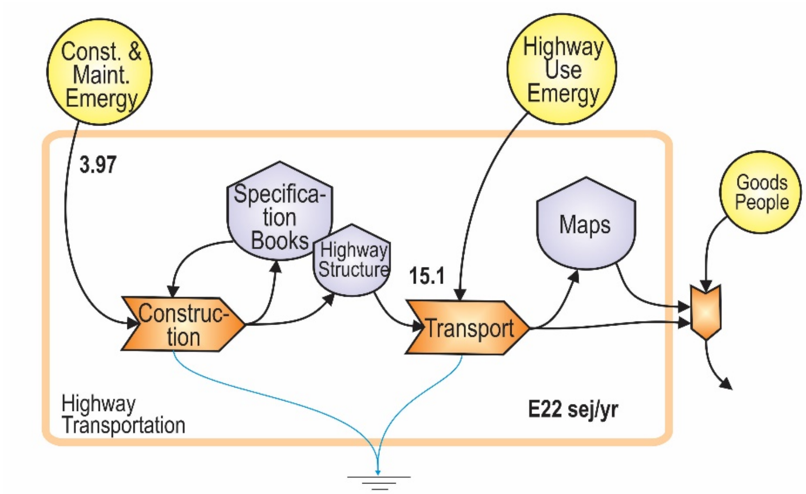

Figure 5. Information Produced in the Texas Highway System. Notice that Specification Books are extracted from the construction process to which they feed-back control. The Maps are extracted from the highway system and are output to highway users, again, for control.

Drawn in the same format as Figure 4, the first aggregated emergy input is shown interacting in highway construction, from which the Specification Books are produced, and the second aggregated input is shown interacting in the usage of the highway for transportation, from which Maps are generated. Hopefully these two diagrams will be useful to readers for conceptualization of the study.

3. Discussion – Spectral Diagram of Highways Hierarchy

With the context of the Texas Highways study now established, I will discuss the results of Odum's quantitative analysis. In the *Crafoord Prize Lectures* (Odum, 1987), the Figure 6 below is included on page 47. His quantitative analysis is in the Endnotes (pages 80-81). I will follow that format here, with my edited version of his quantitative analysis in Appendix A. The quantitative analysis in the appendix is exactly equivalent to that found in Odum (1987, pp. 80-81), but it has been reformatted and annotated for clarity, and several arithmetic errors have been noted and corrected. Emergy researchers should note that those values and the values on Figure 6 have not been adjusted for the newer emergy baselines. The point of this review is not to re-address past values, but to highlight conceptual arguments that were made by Odum. Adjusting the values here would add difficulty for the reader who wishes to compare these values with the original in the *Crafoord Prize Lectures*.

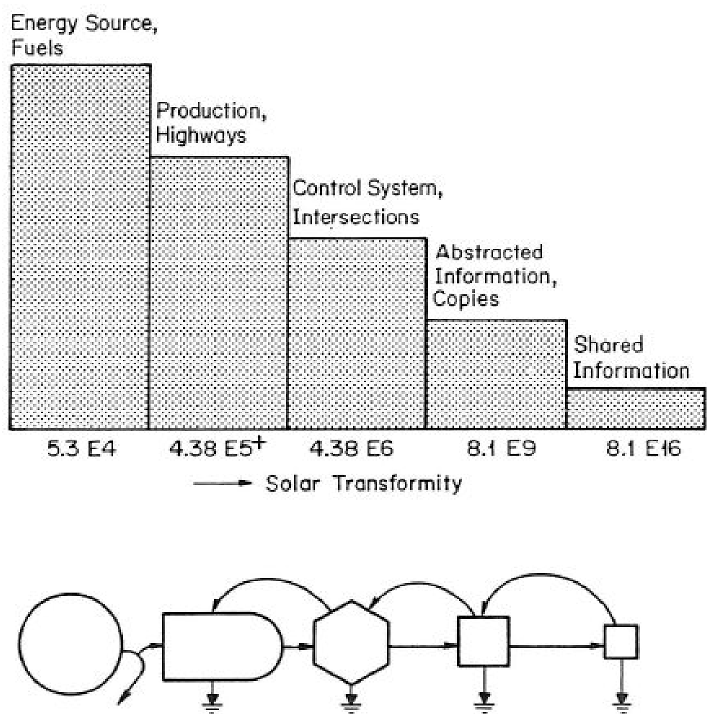

Figure 6. Texas Highway Transformities, units sej/J, used with permission (Odum, 1987, p. 47) (reproduced with permission of the Royal Swedish Academy of Sciences). The 'Abstracted Information, Copies' refers to the highway maps. The 'Shared Information' is the first, 'original' map.

A fundamental energy measure in emergy accounting is *transformity*, and it has been extensively applied in this study.[2] Transformity is an energy measure of hierarchical position (Odum, 1988, p. 1135). Referring to Figure 6 above, Odum says,

"Information is high quality and high in the hierarchy of a system. [In the Texas highway system], the bars represent quantity as a function of solar transformity. The highway system is on the left; maps and booklets of highway specifications are the abstracted information. Road maps in the hands of millions of Texans are shared information, an even higher transformity and influence. Information is higher in hierarchical position than the system where it is used (Odum, 1987, p. 47)."

Notice that 'booklets of highway specifications' were not included in the graph, though they were included in the Endnotes (see Appendix A). I have produced a revised bar graph (Figure 7) that includes the Specification Books. In addition, a revised transformity for the fourth and sixth bars has been substituted, explanation is supplied in Appendix A.

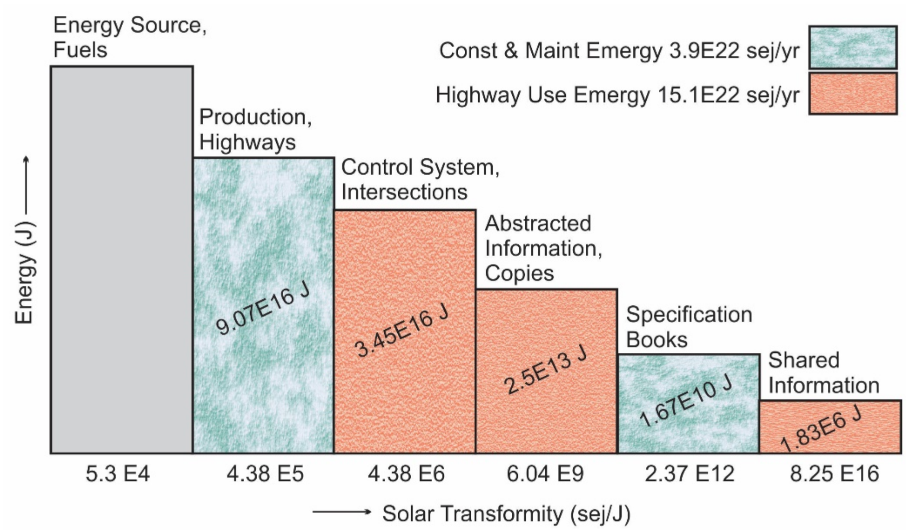

Figure 7. Texas Highway Transformities, Rev 1.

The two aggregated inputs that were referred to above, 'Construction and Maintenance Emergy' and 'Highway Use Emergy' are given values in Figure 7 of 3.9E22 sej/yr and 15.1E22 sej/yr, respectively. These values are from the Endnotes. The first value is used for two transformity calculations. The second is used for three. These are indicated by color in my bar

[2] In recent years, the concept of transformity has been extended to accommodate flows of materials, money, and other units. A general term is now used, the unit emergy value (UEV) to refer to all related measures. As Odum's one focus in this study is emergy per available energy (transformity), I will continue with that terminology, though readers are free to substitute UEV if they desire.

graph. This makes the very important point, which was not directly addressed by Odum, that there are actually two hierarchies included in the bar graph. They are also visible in Figure 5 in the two halves of my diagram. In the quote above, Odum said, "The highway system is on the left… Information is higher in hierarchical position than the system where it is used (Odum, 1987, p. 47)." That is in fact the case for both hierarchies in the bar graph, the material system is on the left and the information that controls it is on the right.

According to Odum, the objective of this study was to construct what he called an energy 'spectral diagram' of hierarchy, with more quantity and energy flow on the left, and higher *quality* but less quantity on the right (Figure 7). This diagram contains transformities for both material processes ('producing' and 'using' a highway) and the information that controls those processes. Per his theory of information (Abel, 2023a), information should be 'extracted' from the material world, and miniaturized. In that event, less energy is used to produce information (specification books and maps), and therefore the transformities of information should be larger than the transformities for the material processes that they control. This is indeed the case, as the bar for 'Specification Books' is to the right of 'Production, Highways', and the two bars for 'Highway Use' information, 'Abstracted Information, Copies' (Maps) and 'Shared Information' (the first Original Map), are to the right of the bar for highway use, 'Control System, Intersections'. For Odum, this hierarchical result was the fundamental contribution of the study.

3.1 Discussion – Parallel Cycles for Texas Highways

The Parallel Cycles model (Figure 3) is reproduced below (Figure 8) to demonstrate the application of Odum's concepts and numbers on the diagram. Energy values are in J/yr, and transformities (Tr) are in sej/J. Note that the same aggregate emergy values are plainly seen on this diagram, Construct and Maintain the Highway (3.97E22 sej/yr) and the emergy of the Highway In Use (15.1E22 sej/yr). Those values in their respective information cycles are divided by the energy inputs (J/yr) to produce the transformities (Tr, sej/J) that are shown on the diagram. These are the same transformities as in Figure 6.

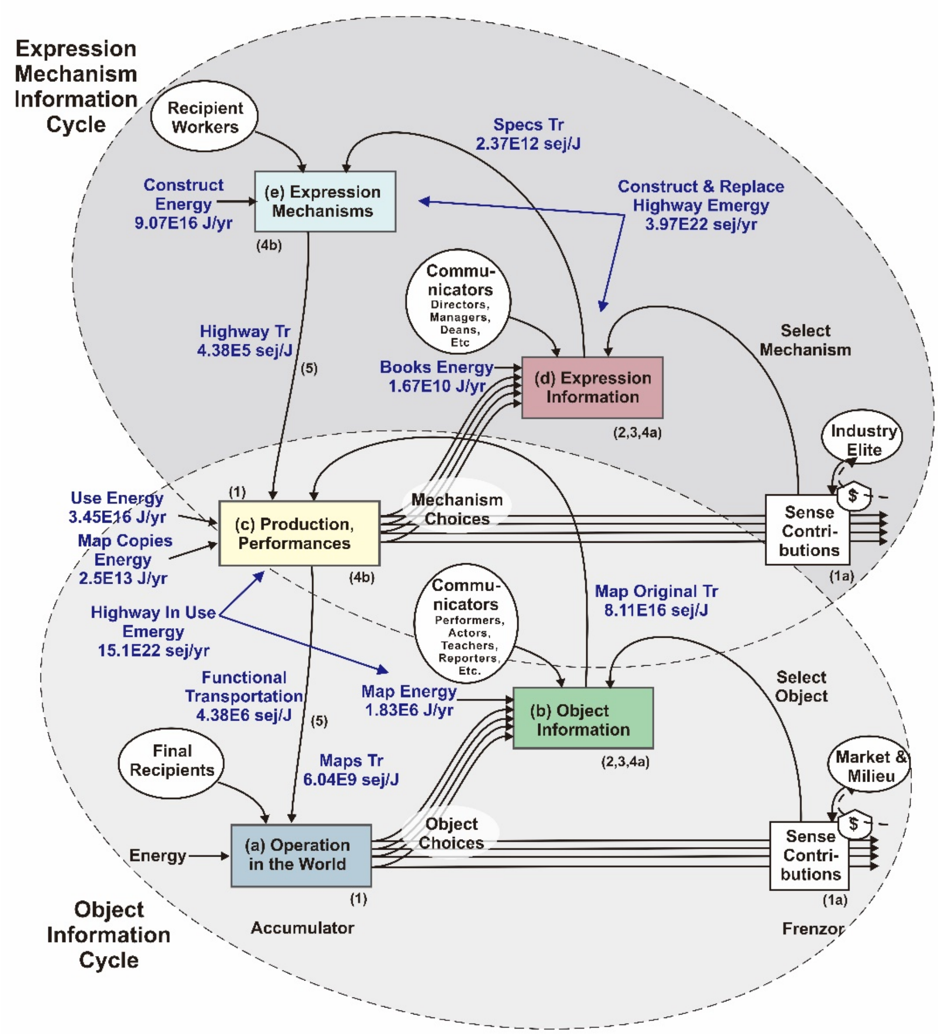

Figure 8. Parallel Cycles with Texas Highway Demonstration. All added labels and values are from the demonstration in Appendix A. 'Construct & Replace Highway Emergy' and 'Highway in Use Emergy' are my two labels for the total emergy inputs to each of the parallel cycles. Recall that the information cycle step numbers are labeled 1,1a,2,3,4,5, while the subsystem processes are labeled a,b,c,d,e.

As I now understand Odum's original analysis, he was conducting two analyses, both with a physical product and the information required to control that production. When their transformities were graphed, we should expect a hierarchy (spectral) shape with the physical product on the left and the information on the right. For the products of human culture, we should always expect these pairs of pairs – physical system : expression information, and performance : information object. Readers are suggested to walk through the diagram as before, noting the key ingredients for calculating transformities, the system emergies and the energy flows that enter process boxes. Output flows are labeled with the transformities of the outputs.

Comparing this diagram to Figure 4, the focus and purpose is obviously different with highly aggregated energy inputs, in comparison to the itemized inputs in the earlier figure. My suggestion is that both style of diagrams are necessary for reporting on systems with information.

4. Conclusions

This paper has demonstrated the utility of the parallel cycles model for emergy researchers and other scientists for the conception of information in DNA, symbolic culture, or manufactured object. The thesis of this paper has been that information requires parallel cycles of information production and maintenance. DNA contains the information blueprint for a new cell or body. In addition, the information of DNA includes the information needed to *direct* the reproduction of DNA (in new cells or bodies), i.e., it includes also the ‘expression information’. Culture likewise requires both ‘object information’ and ‘expression information’, however there is no single ‘body’ in which they reside. In order to fully represent the information of culture, we need to search for and identify these two related forms when we wish to study or write about culture and cultural transmission. Because information is always ‘carried’ on material carriers, we must also explain how that information *persists* when carriers naturally depreciate (Second Law). This brings us to the *parallel cycles* of information production and reproduction that are described in this paper.

It may be necessary to broaden the definition of ‘information’. Information is something produced in parallel information cycles, one for the information ‘essence’ or meaning or content, and one for the ‘recipe’ for the production of that information. Both are maintained against depreciation in information cycles of selection, extraction, copy, and dispersal. In living organisms, these two types of information are together within an organism that is designed to use both of them in reproduction. In culture, both material and symbolic, they are distinct, parallel cycles.

Note. Emergy Webinar

In the summer of 2022, an emergy webinar entitled “Information Emergy: What Were Odum’s Intentions?” was presented (Abel, 2022). The content of that webinar was addressed to three papers that are now published. One is this paper, the other two are “Evaluating information with emergy: How did Howard T. Odum incorporate human information into emergy accounting?” (Abel, 2023b), and “An emergy analysis of cultural information: tackling the most difficult problem in ecological economics" (Abel, 2024). The reader is invited to view the webinar at the link in the References.

References

Abel, T., 2013, Emergy evaluation of DNA and culture in 'information cycles'. Ecological Modelling 251: 85-98. https://dx.doi.org/10.1016/j.ecolmodel.2012.11.027

Abel, T., 2014, Culture in Cycles: Considering H.T. Odum's 'Information Cycle'. International Journal of General Systems 43(1): 44-74. https://dx.doi.org/10.1080/03081079.2013.852188

Abel, T., 2015, Cultural Transmission in Cycles: The Production and Maintenance of Cumulative Culture. Journal of Cognition and Culture 15: 443-492. https://doi.org/10.1163/15685373-12342161

Abel, T. (2016). *Pools of Money: Information Cycles for the Production and Maintenance of Financial Information*. Paper presented at the 9th Biennial Emergy Research Conference, Gainesville, FL.

Abel, T., 2017, Manufacturing in Cycles: Tertiary No More. Paper presented at the International Society for Ecological Modelling Global Conference (ISEM 2017), Jeju, Korea.

Abel, T., 2019, Information and Service in Emergy Analyses. [In] M. T. Brown, S. Sweeney, D. E. Campbell, S. Huang, T. Rydberg, & S. Ulgiati (Eds.), Emergy Synthesis 10: Theory and Applications of the Emergy Methodology. Proceedings of the 10th Biennial Emergy Conference. 97-108. Gainesville, FL: The Center for Environmental Policy.

Abel, T., 2022, 10 June, 2022. Information Emergy - Emergy Webinar 2.0. Retrieved from https://youtu.be/wapjx-sxrWY

Abel, T., 2023a, Building With/On HT Odum's Theory of Information. International Journal of General Systems. https://doi.org/10.1080/03081079.2022.2162048

Abel, T., 2023b, Evaluating Information with Emergy: How Did Howard T. Odum Incorporate Human Information into Emergy Accounting? Discover Environment 1,9. https://doi.org/10.1007/s44274-023-00007-z

Abel, T., 2024, An Emergy Analysis of Cultural Information: Tackling the Most Difficult Problem in Ecological Economics. Journal of Environmental Accounting and Management, 12(2): 169-184. https://doi.org/10.5890/JEAM.2024.06.005

Brown, M. T., 2015, Emergy and Form: Accounting Principles for Recycle Pathways. Journal of Environmental Accounting and Management 3(3): 259-274.

Campbell, D. E., & Lu, H., 2014, Emergy Evaluation of Formal Education in the United States: 1870 to 2011. Systems 2: 328-365.

Lyu, W., 1986, Emergy analysis of highway transportation in Texas, unpublished class report. [In] H. T. Odum, E. C. Odum, & M. Blissett (Eds.), The Texas System (pp. 130-157). University of Texas, Austin: LBJ School of Public Affairs.

Odum, H. T., 1971, Environment, Power and Society. New York: Wiley.

Odum, H. T., 1977, The Ecosystem, Energy, and Human Values. Zygon 12(2): 109-133.

Odum, H. T., 1983, Systems Ecology. New York: John Wiley.

Odum, H. T., 1987, Living with Complexity. [In] The Crafoord Prize in the Biosciences 1987 (pp. 19-85). Stockholm, Sweden: The Royal Swedish Academy of Sciences.

Odum, H. T., 1988, Self-Organization, Transformity, and Information. Science, 242(4882): 1132-1139. https://doi.org/10.1126/science.242.4882.1132

Odum, H. T., 1989, July 2-7, 1989. Emergy and Evolution. Paper presented at the 33rd Annual Meeting of the International Society for the Systems Sciences, Edinburgh, Scotland.
Odum, H. T., 1995, Self-Organization and Maximum Empower. [In] C. A. S. Hall (Ed.), Maximum Power: The Ideas and Applications of H.T. Odum (pp. 311-330). Niwot, CO: University Press of Colorado.
Odum, H. T., 1996, Environmental Accounting: Emergy and Decision Making. New York: John Wiley.
Odum, H. T., 1999a, Limits of Information and Biodiversity. [In] H. Loffler & E. W. Streissler (Eds.), Sozialpolitik und Okologieprobleme der Zukunft (pp. 229-269). Vienna: Osterreichischen Akademie der Wissenschaften.
Odum, H. T., 1999b, Material Circulation, Energy Hierarchy, and Building Construction. Paper presented at the Riniker Eminent Scholar Workshop on Construction Ecology and Metabolism, University of Florida, Gainesville.
Odum, H. T., 2007, Environment, Power, and Society for the Twenty-First Century: The Hierarchy of Energy. New York: Columbia University Press.
Odum, H. T., & Odum, E. C., 1976, Energy Basis for Man and Nature. New York: McGraw-Hill.
Ulgiati, S., & Brown, M. T., 2014, Labor and Services as Information Carriers in Emergy-LCA Accounting. Journal of Environmental Accounting and Management, 2(2): 163-170.