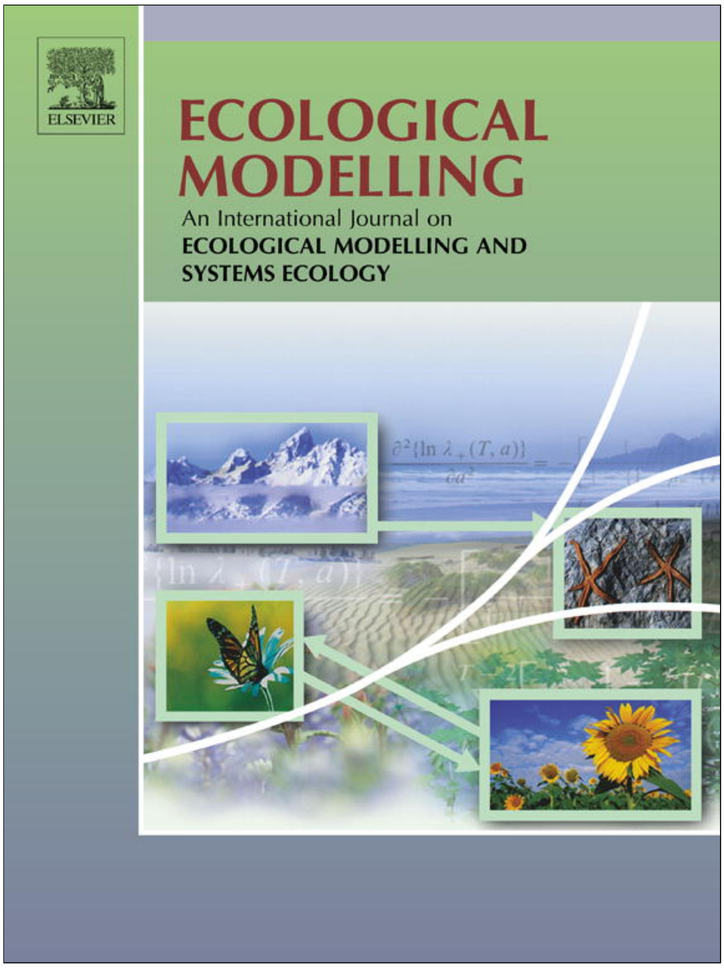
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Emergy evaluation of DNA and culture in 'information cycles'

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ABSTRACT

Explication of the 'information cycle' and its energy basis is a crowning component of H.T. Odum's theorizing of general systems. This paper applies the information cycle to cultural information. Specifically, the information cycle concept is applied to one domain of information production, regular conversation. The transformities of conversation production are estimated by adopting principles from Odum's rainforest examples where he estimated transformities of information flows of various kinds, specifically, the emergy to copy units containing information, emergy to isolate and extract information, emergy to sustain an information cycle, and emergy to develop new information. The second and third kinds have been evaluated for conversation. Transformities of conversation follow a similar pattern of increasing values (2.21E15 and 1.50E16 sej/J, respectively). These results are compared with two other studies of cultural information production, one for television media and one for education. Taken together, these results suggest that cultural information is in fact a nested hierarchy of cultural information scales, with transformities that increase in order, with conversation first, then media, and finally education. This paper indicates how conversation can be illuminated as an information cycle, and located in a hierarchy of information production.

1. Introduction

While it is widely known that systems ecologist H.T. Odum sought an understanding of energy and material flows and processes within systems of all kinds, it is equally true that he was fascinated with the role of information within those same systems, and over time developed an original conceptualization of information that addressed its forms (both genetic and cultural), its maintenance against Second Law depreciation, and its contribution to system self-organization (Odum, 1983, 1996, 2007; Odum and Odum, 1976). His approach can be distinguished immediately from standard 'information theory' for his objections to the 'log-of-possibilities' measure that is characteristically utilized (Shannon and Weaver, 1949), which he says "gives the same value to useful information that has been selected through reinforcement during self-organization to operate systems as it does to useless complexity that will not operate anything" (1996:237). For Odum, useful information is fundamentally a product of the self-organization of systems, wherein its function is to remember successful configurations – of cells, organisms, ecosystems, and, of particular interest for this paper, human adaptations.

Odum's well-known concept of *emergy* for 'energy memory' is a means to distinguish different 'qualities' of energy. The joules of energy in sunlight are different from joules of leaf biomass, which differ from joules of electricity, which differ from joules of hawk metabolism in the hunt, which differ from joules of sound waves in human conversation, which differ from joules of tree species genetic material. They differ because progressively they took more and more work in past processes that made their production possible. Emergy quantifies that past work. It is thus an ideal measure to quantify the past work required to make useful information, and to distinguish it from useless complexity. As Odum says, "useless complexity – in which little work has been exerted to make it useful – has low emergy, whereas highly evolved and adapted complexity has high emergy because of the larger and longer flows of emergy required for its development and maintenance" (1996:238).

In (Odum, 1988), Odum began the work of calculating the emergy of information. But it was in *Environmental Accounting* (Odum, 1996), that he provided his most detailed description of the procedure necessary, which included a theoretical treatise on information, its production and, importantly, its maintenance (1996:220–230). In a demonstration that utilized data from the Luquillo rainforest in Puerto Rico, Odum takes us through the steps of calculating information transformities for rainforest processes – duplicating tree leaves, growing seeds, maintaining a tree species population, and developing a new tree species. In this paper, I will expound upon Odum's analyses, taking issue with parts, and clarifying some points that were perhaps too concise, and I will then apply his approach to a uniquely human scale of information production – conversation. The result will be the calculation of conversation

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transformities that are analogous to three of the four rainforest processes that were calculated by Odum. This exercise will clarify and standardize the procedure for calculating information transformities, especially as it can be applied to 'cultural' information. This will prepare the way for emergy analyses of 'scales' of cultural information other than conversation.

2. Self-organization and the role of information

Self-organization is argued to be a fundamental phenomenon of nature, the result of nature's thermodynamic arrow in time (Prigogine, 1980). Once labeled 'heat death', nature's entropic directionality from concentration to dissipation is today recognized to be a creative force by which self-organized structures appear (Depew and Weber, 1995; Odum, 1983; Prigogine, 1980; Schneider and Sagan, 2005; Ulanowicz, 1997; Wicken, 1987). Self-organized structures perform work in self-reinforcing ways as they reduce natural energy gradients (Odum, 1996).

When a self-organized structure loses its energy source, like when a typhoon moves on land, its structure is quickly lost. The next typhoon must start again, without memory of any previous storm to guide it, slowly finding its form. In contrast, the genetic information of life allows self-organized structure to persist in time and extend in space, to ride-out the many natural fluctuations in energy sources (e.g., day/night, seasons, etc.). With the appearance of life, time-tested energy pathways are preserved from day to day, and much longer, by the information of genetics and its blueprint for both living and reproduction (Odum, 2007:221).

Once created, therefore, genetic information is of great value to life and any system of which it is a part. Information does not exist in abstraction, but is always 'carried' by some material or energetic form. It can thus be lost when carriers depreciate per the Second Law of Thermodynamics. In order to prevent loss, information must be copied to a new carrier. But copying can produce errors. The solution that nature has found is to produce many copies of genetic information, to release them into the world, and, eventually, to select among them the best functioning copies for a next round of copying. In biology this cycle is the reproductive cycle with natural selection. Odum has generalized this flow of information selection, extraction, duplication and dispersal into what he calls the information cycle (Fig. 1). In order to prevent loss, information must be transmitted through time via many copies in an information cycle, via a population of carriers bearing that information (Odum, 2007:88–89).

3. Scales of cultural information in a hierarchy of culture

With the evolution of humans a new form of information has appeared. Generically we call it *culture*. Odum has elaborated the lifecycles of rainforest trees (Odum and Odum, 2001:72), of salmon (Odum, 2007:228), and of shrimp (Odum, 1996:228) as information cycles, however, he never provided a detailed account of the formation of cultural information. Abel (submitted for publication-a) offers a theoretical framework for the application of the information cycle to the production of 'culture'. It is argued that culture is shared in a hierarchy of distinct 'scales' of information production (including memory, conversation, media, ritual, education, research, and legal codes, Fig. 2). These scales differ in a number of critical dimensions, such as how quickly they degrade, how widely they are shared, how much work is required for their construction, energy and material inputs, feedback impact, fidelity of intermediate carriers, and in the number of production events.

Consider for example the inputs to a news story that are supplied by news corporations operating newsrooms, satellite and cable transmission networks, or printing presses and transport vehicles, employing reporters and managers, and producing news stories every few hours. Compare that to an academic publication that is the product of a scholar at a research university, who requires sophisticated equipment, employs highly trained graduate students, and requires years between each publication product, which, as news stories, must be distributed around the world, both electronically and in paper to elaborate storage facilities known as libraries. Now consider conversation, the subject of this paper, in which energy inputs are primarily human metabolism, and outputs are speech energy. Emergy analyses of the different 'scales' of cultural information are underway (Abel, submitted for publication-b, submitted for publication-c) or planned. This paper with its emergy analysis of conversation is special, however, because of its careful consideration and comparison to Odum's rainforest demonstration.

This paper will look closely at the cyclical process of information production in conversation and the inputs to that process. While input data is empirical or estimated from empirical measurements, it is the demonstration of the methodology for evaluating cultural information that is at the heart of this paper. At this point, published emergy analyses that included humans have only coarsely estimated human inputs from aggregate, whole-system measurements (Abel, submitted for publication-a; Odum, 1988). This research should thus benefit both conceptually and methodologically the emergy analysis of the many worldwide nature–culture systems in which human inputs of information need be included.

4. The hierarchical organization of culture and mind

Past definitions of culture included shared ideas, beliefs, artifacts and performance (Kroeber and Kluckhohn, 1952). Today, social scientists generally take a narrower view in which 'culture' is meaning or knowledge in mind and body, and the artifacts, behaviors, and performances that we observe are the products of that knowledge (D'Andrade, 1995). Furthermore, culture is no longer understood to be universally shared and slavishly followed, but rather it is socially distributed, variously internalized, and actively contested or negotiated among groups and subgroups within a community (Foucault, 1980; Comaroff and Comaroff, 1991; Gramsci and Buttigieg, 1992; D'Andrade, 1995). If culture is *located* somewhere, therefore, it is located within us, within our minds and bodies, and it is the constructed product of our interactions with others and with the cultural information produced at the additional scales of Fig. 2.

Within each person, within their memories, the structure of cultural knowledge is complex. I have argued that it can be represented as a hierarchy (Fig. 3) (Abel, submitted for publication-a). This is not the place for extensive discussion, but it can be said that 'culture' is not simply the conscious, declarative knowledge that we equate to a conversation topic, for example. The episodic memory of a conversation may stay with us for some time. Likewise, the explicit memory of an experience with television or printed media, with a ritual event, or with an academic article, for example, are all sources of declarative knowledge that we hold consciously in memory. But *explicit* declarative knowledge in memory, anthropologists have long argued (Bourdieu, 1977; Holland and Quinn, 1987), is input to the construction of *implicit* knowledge, which I represent as a hierarchy of cultural knowledge in memory (Fig. 3). Implicit cultural knowledge is the statistical product of input (Saffran, 2003). It is constructed from countless interactions with information, most importantly from parents and peers in the earlier years of life.

This second information hierarchy has special qualities. The information forms that are at larger scales, those of semantic domains, linguistic postulates, schemas, even cultural models, are largely unrecognized by language users. They are the 'rails of thought', the *implicit*, taken-for-granted understandings of the world that language communities and culture members variously

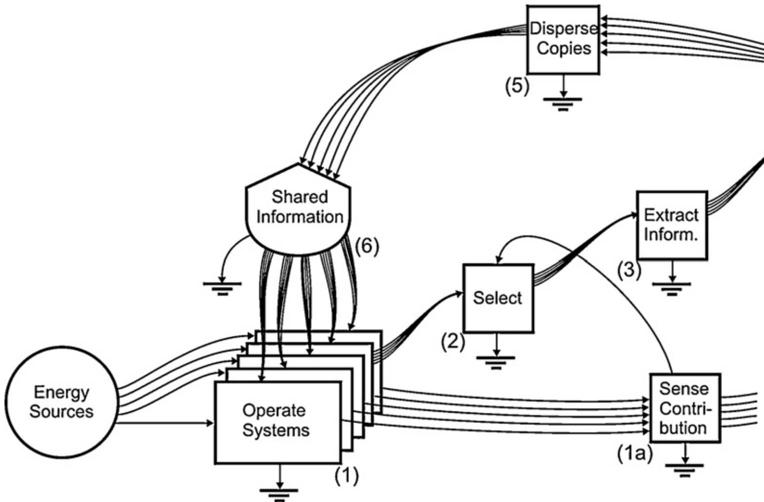

Fig. 1. The information cycle. An information cycle as diagrammed by H.T. Odum (Odum, 1996:223, step numbers added, used with permission). This general model applies to the production and maintenance of all forms of information. Regarding the genetic information of life we observe a life-cycle in which *natural selection* (1a and 2) chooses successful mating pairs from which DNA information is *extracted* (3) and *copied* (4) to offspring, which then *disperse* (5) to live their lives in the larger *world* (1) where they may or may not be chosen to transmit their DNA to the future. Cultural information is also maintained in information cycles, as discussed in the text.

share. As in other hierarchies, the larger scales control or structure the behaviors to their left (feedback arrows). Only at the first, *explicit*, declarative scale are the producers of information consciously attuned to the arguments they make, which themselves are constrained by the larger scales.

The point of this introduction is to make clear that 'culture' is not simply a collection of shared conversation topics, event memories, declarative knowledge, or other consciously held beliefs, ideas, or values. Explicit knowledge in speech, news story, journal article, these are sources of input to the construction of implicit cultural knowledge within each of us. As I explore the production of 'shared' cultural information in this paper, I will at times address explicit knowledge in the specific content of conversation topics. At other times I will consider shared cultural content that is more schematic and implicit. It is this latter form that is expected to be the most widely shared within a language and culture community as action and speech events repeat often in form, if not in detail, abetting the construction of human cultural knowledge.

5. Kinds of information duplication – Odum's demonstration

Odum published only a few emergy analyses of information. His most detailed example is a study of rainforest trees on the island of Puerto Rico (Odum, 1996:222–225), which I am using as a blueprint for information cycle analysis applied to culture. In a brief but rather dense account, Odum contrasts four different processes or *kinds* (in his terms) of information duplication. While genetic information and its biological processing are clearly his inspiration, he is arguing that any form of information should be fit to the model, and he therefore attempts to generalize the language applied. Thus, his four kinds of information duplication are: (I) simple copying

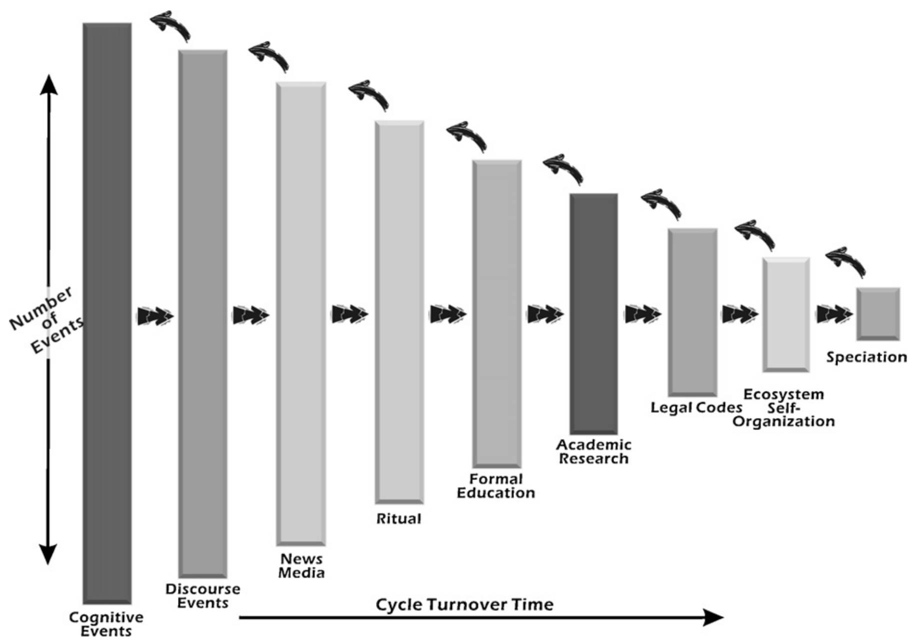

Fig. 2. Hierarchy of Cultural Information Scales. These 'process' boxes are intended to represent each of the different scales or modes of cultural information (Abel, submitted for publication-a). This is a general model that applies to the cultural information of any current industrial society.

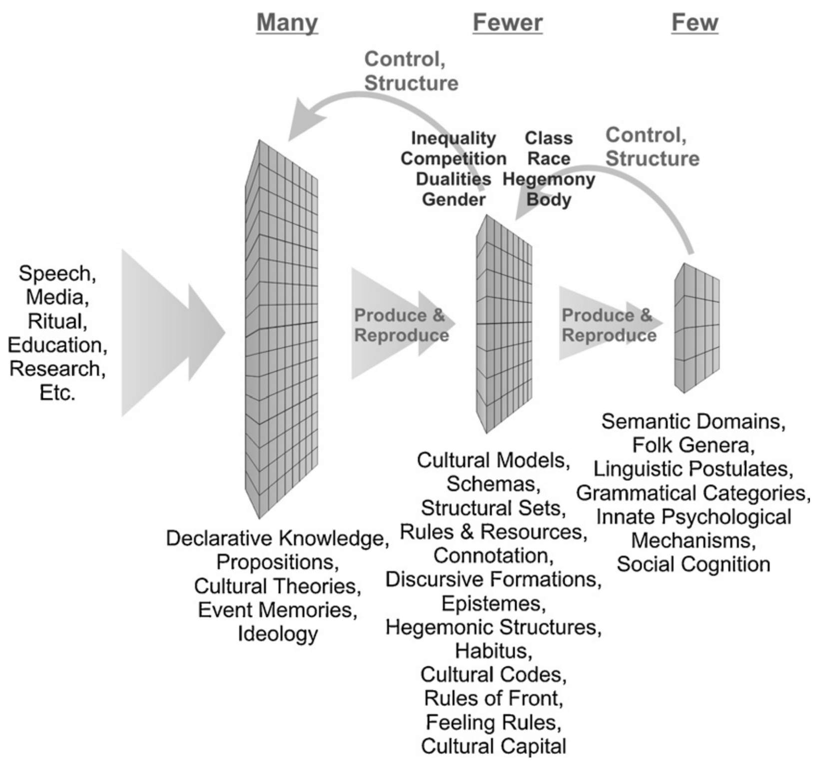

Fig. 3. Hierarchy of cultural knowledge in mind and body. The cultural information within any individual is actively (re-)constructed as we engage in human communication at any scale, speech, media, ritual, etc. The first scale in this schematic drawing is explicit, declarative knowledge. The second two scales are implicit knowledge that we construct over time or that is innate. Many social scientists have proposed theory and labels for this type of knowledge, and some are included here as demonstration. As in other hierarchies, there are many events in the scale to the left (everyday conversations, media experiences, etc.), fewer objects in the middle, and fewer still to the right. While some objects to the right have an innate component, their expression is a ‘product’ of those to the left. Simultaneously, objects to the right feedback to control or structure or constrain those on the left.

of information, (II) isolating and extracting information into compact form (which occurs in biological reproduction with seed or egg), (III) sustaining (widely) shared information, and (IV) developing (new) useful information. The label for the second form is long and somewhat unwieldy, and I frequently use the shorthand ‘*reproducing* information.’ The four kinds of information duplication are outlined in Table 1.

The partitioning of information duplication that Odum makes into four forms is brimming with conceptual implications. Briefly it can be stated that the partitioning relates to the *dispersal* of information in environments, which is essential to information persistence, and which in turn is indicative of the functional value of any information to the systems it inhabits (i.e., wide dispersal indicates value). Recall again that the function of information is related to preserving time-tested energy pathways within self-organizing systems, and thus the most useful information should be that which is widely shared and consistently reproduced within a population of carriers. The distinctions that Odum makes in kinds of information duplication, therefore, are of great interest. His approach deserves emulation in application to non-genetic information forms, if not at least to test its generality, but more hopefully to see what insights can be gained.

In the rainforest study, therefore, Odum actually performed four separate analyses, each related to a different *kind* of information duplication that included: (I) copying, (II) reproducing (again, which includes ‘extracting’ information into compact form of seed, egg, etc.), (III) sustaining, and (IV) creating information, which parallel roughly mitosis, reproduction, positive selection, and speciation. Each of the kinds of information duplication is achieved *via* information cycles. Some confusion arises with Odum’s use of the words ‘copying’ and ‘extracting’ to describe two distinct kinds of information duplication (I and II) since the same words are used for two *steps* in the information cycle (Fig. 1, steps 4 and 3). In both cases they are not equivalent, but rather in one instance they characterize two distinct *forms of duplication processes*, and in the other

Table 1
Information ‘Kinds’ summary and comparison. The four kinds of information duplication and the number of cycles required for duplication are listed below together with a description of their outcomes when applied to rainforest trees and to conversation. Transformities for each of these are calculated by Odum for his rainforest demonstration. They will be calculated in this paper for conversation. They could also be evaluated for any of the other scales of cultural information, i.e., media, ritual, education, etc.

Kind of duplication	Number of cycles	Rainforest trees	Conversation
(I) Copying Units Containing Information	One (Many?)	Duplicating tree leaves	Re-broadcast information in memory
(II) Reproducing Information – Isolate and Extract Information in Compact Form	One	Production and dispersal of seeds	One conversation and dispersal of people
(III) Sustaining Shared Information	Many	Sustained species	Sustained conversation topic
(IV) Creating New Information – Develop Useful Information	Many more, with mutation and selection	Species formation	The formation of a new cultural variant

they label two *steps* in *any* information cycle. This important point will be further clarified below.

Among Odum's four kinds of information duplication, cycle times are shortest with copying and longest for creating information. Odum explains the workings of these information cycles through a series of related examples, each demonstrated with data from the Luquillo rainforest in Puerto Rico. It is therefore necessary to review each of his examples before applying the same methods to the analysis of conversation information (these same methods could also be applied to the other information scales of media, ritual, education, research, etc., though in my summary I will recommend one 'kind' over the others). Following my narrative of Odum's examples, I will present an analogous demonstration of conversation information. The analogous kinds of cultural information might be labeled (I) memory events, (II) conversation, (III) maintaining shared information (culture) in a population of conversations, and (IV) new cultural information.

As stated above, Odum's accompanying text is brief and at times sketchy, and some effort has been made in each case to elaborate upon his most likely intended meanings. I will save the first case for last, because I believe that it raises additional issues that will distract from the central narrative of this paper. I will therefore begin with the second kind of information duplication, 'emergy to isolate and extract information into compact form', or the *reproduction* of information.

5.1. Rainforest emergy to isolate and extract information in compact form (Kind II)

The emergy to isolate and extract information into compact form is the emergy of *one* information cycle (Table 1). In a lifecycle of a tree, this is the production and dispersal of seeds (Fig. 1). Odum chooses to demonstrate this process on a per hectare basis, probably because that is the spatial scale at which emergy data is known, and because it accommodates spatial variability in the rainforest. But there are two additional explanations and implications of doing this. First, trees are part of the eco*system*, and although the immediate tree environment may appear to constitute the tree's boundary, an ecosystem we know is remarkably complex and interconnected and the tree, arguably, could not exist without the forest and the work done by the whole (in soil production, seed transport, etc.) in support of the parts.

This relates, second, to the question of why the trees are assigned the total forest emergy. While tropical rainforests do support lower canopies of subdominant trees with lianas, shrubs, and ground vegetation and a uniquely rich canopy of epiphytes, they are, generally speaking, hollow forests. About 80% of the ecosystem biomass occurs as woody tissues of trees and 5% as foliage in an extremely dense canopy high above the forest floor. This leaves only 15% of the organic matter in soil and litter. Thus Odum is treating the rainforest trees as the approximate total of the *scale* 'plant producers,' which therefore receives the total emergy of the system. It may also be, though this is not stated, that Odum is conceptualizing a hierarchy of plant species, with trees in a scale by themselves, which thus receive the total emergy.

The emergy required for an information flow or storage is the sum of the emergy contributions to the process. In Odum's example, the 'emergy support flow' is the annual emergy support to the forest (1 ha) times the replacement time, which is one year for the trees. The 'information carrier flow' is the DNA flow in all seedfalls (1 ha) times the replacement time of one year (see Table 2 for a comparison of these variables for each kind of duplication for both rainforest trees and conversation). Odum is thus calculating a transformity at Step 4 (Fig. 1), the 'Make copies' stage. Transformities are different for each step in the information cycle because the carriers are different. Odum has stated that one information copy from Step 4 should have the largest transformity because the energy is now split into many different individual carriers (seeds or eggs) with identical information (Odum, 1996:227). Odum chooses the transformities for Step 4 as the benchmark value for any information cycle, and I will use this same convention with cultural information. Eq. (1) is the transformity of information in DNA in the reproduction of rainforest trees.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{6.0\text{E}14\ \text{sej/ha/yr}}{5.33\text{E}5\ \text{J DNA/ha/yr}} = 1.126\text{E}9\ \text{sej/J DNA} \quad (1)$$

5.2. Rainforest emergy for sustaining shared information (Kind III)

Sustaining shared information is the third kind of information that Odum evaluates. It is the emergy that is required to keep a unit of information *functional*. Per the Second Law of Thermodynamics, any storage will depreciate. Information that depreciates or degrades will loose its functionality, and if this occurs before it is copied the information will be lost. It is for this reason that information is maintained by a *population* of information carriers, each of which reproduces its information in the population's information cycle. In the most familiar example, the information cycle of natural selection requires a reproducing population of organisms to maintain genetic information. Most genetic information in a reproducing population is 'shared information'. Shared information has special qualities:

> An item of information that is shared—held by many units—has the greater emergy that copied and established it in many units, but its territory is now much bigger than any one carrier and its effect is larger, its time constant longer, and its depreciation less than those of any one carrier (Odum, 1996:225–227).

In other words, shared information is more difficult to lose. It is in effect insulated from loss because it must be lost from each carrier (over a larger 'territory', which takes more time, i.e., 'its time constant is longer'). It may even spread to different environments where it occupies a different role, which further insulates it from loss. Information that is shared over a large territory of one or many environments must be functional in each, and thus, in total, 'its effect is larger.'

The emergy needed to maintain shared information is greater than that to maintain the first two kinds of information duplication. The emergy needed is the emergy to maintain a *population*. Information that is useful is *repeatedly* passed through the information cycle (Fig. 1), being (2) *selected* at each turn, *extracted* (3), *copied* (4) and *dispersed* (5). The emergy to maintain information by maintaining the population can also be called the "emergy of shared information."

In the rainforest example, this is the emergy to maintain a tree species population via natural selection. For the sake of evaluation it is not necessary to witness repeated cycling. Apparently, in Odum's reckoning, a species is being sustained if it exists, and so we do not need to prove it with many passes through its information cycle. One tree cycle is one year, in which a new seedfall is produced. The emergy required is that to support one species for one year. It requires the total species population for maintenance. Thus the 'emergy support flow' is the annual emergy support to the entire forest, but per species count (153 species) (contrast this with the first demonstration in which DNA is not distinguished by species because in only one cycle 'sharing' information within a species is irrelevant). The 'information carrier flow' is the DNA flow for *one* tree, per year. This reflects the fact that one copy of DNA information

Table 2
Transformity variables. This table summarizes the transformity calculations for each of the Kinds of information production. Two variables are required for each transformity calculation. These are 'emergy support flow' and 'information carrier flow.' For each of the four Kinds, these variables are briefly explained. For Kind I, at the bottom of the table, there are no equivalent conversation variables because that calculation is not made in the text.

Transformity variables	Rainforest trees	Conversation
(II) Reproducing information – isolate and extract information in compact form		
Emergy support flow	Annual emergy support to the forest (1 ha) × seed replacement time (1 year)	Annual emergy support to 2.5 persons × conversation time (9 min)
Information carrier flow – sender	DNA flow in seedfalls (1 ha) × replacement time (1 year)	Energy of *speech carrier waves* for 9 min conversation
(III) Sustaining shared information		
Emergy support flow	Annual emergy support to the *entire* forest, but *per species* count (153, so emergy of 128 ha of forest), i.e., shared information requires a *population* for maintenance	Annual emergy support to some area (campus) to sustain one conversation among other shared conversations × shared conversation duration (2 weeks)
Information carrier flow – sender	DNA flow for *one tree*, per year	Energy of *speech carrier waves* for one sustained conversation topic
(IV) Creating new information – develop useful information		
Emergy support flow	Per species emergy support flow as #3 above, times 10,000 years to evolve new species	Total cultural emergy per topic, *at the appropriate cultural information scale* (conversation), for time between successive innovations
Information carrier flow – sender	DNA flow per tree as in #3 above (slightly higher value unexplained)	Energy of *speech carrier waves* for one sustained conversation topic (same as #3)
(I) Copying units containing information		
Emergy support flow	Annual emergy support to the forest (1 ha) × leaf replacement time (1.5 years)	N/A
Information carrier flow – sender	DNA flow in leaves (1 ha) × replacement time (1.5 years)	N/A

requires the entire population for its maintenance. Each member of the population is considered to carry similar genetic information. Eq. (2) is the transformity of information in DNA that is shared by a tree species.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{7.7\text{E}16\ \text{sej/species/yr}}{1.06\text{E}5\ \text{J DNA/tree/yr}} = 7.26\text{E}11\ \text{sej/J DNA} \tag{2}$$

5.3. *Rainforest emergy to develop useful information (Kind IV)*

The emergy for new useful information development is the largest of the several emergy measures of information because more resources are required to make a unit anew than to copy, share, and select an old unit.

> Emergy to develop new, useful information is that [emergy] required to make at least one copy of *new* information from its precursor. For example, the development emergy of a new species of tree is the emergy required to operate the population over the time period required for its evolutionary changes (Odum, 1996:225).

In order to apply this last form of information production to cultural information, the concepts of evolution and speciation need to be examined. Microevolution in any biological population is persistent and will permit fine adaptations to environments. The testing and wide sharing of small changes is addressed in Odum's scheme in the previous section on information sharing. When Odum refers to the development of new useful information (quoted above), he is referring to the macroevolution of a new species. As he states above, the time required for the formation of a new species is the time period 'for its evolutionary changes', i.e., for the many microevolutionary changes that distinguish one species from another.

In the rainforest example, the per species emergy support is calculated as before, taking the total emergy of the forest and dividing by the number of tree species, however, that number is multiplied by 10,000 years for the time required to develop a new species. The information carrier flow is again the DNA content of one individual. Eq. (3) is the transformity of information in DNA that is shared by a newly evolved tree species.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{7.7\text{E}16\ \text{sej/species/yr}}{1.59\text{E}5\ \text{J DNA/ind}} = 4.8\text{E}15\ \text{sej/J DNA} \tag{3}$$

5.4. *Rainforest emergy to copy units containing information (Kind I)*

Finally, we return to Odum's first example. I delayed this section because, as I said, I felt it would distract from the central narrative. Indeed it would, for I believe that (in this case only) Odum's identification of a fourth, distinct 'kind' of information production is mistaken. In Odum's account, he states that very little emergy is required to make one copy of units of any kind that contain information (1996:222–223). He gives two examples: the "duplication" of tree leaves (which he also calls "simple biological reproduction") and making a copy of a page of text on a copier machine. Odum's discussion of this process is exceptionally brief, to the point of being incomplete. As evidence, first, he does not explicitly characterize 'photocopying' as an information cycle. Second, if we consider carefully the biology of leaf 'copying' then we are considering plant growth and the information sharing process of mitosis. Nowhere in Odum's brief account does he use the word mitosis, but if he had it would be clear that this is a cell-by-cell process of duplication, and not whole organism duplication as in the other three cases. The distinction, I would argue, is one of scale: cell versus organism.

Choosing a leaf as an object of copying is an odd choice. Certainly a page of text is an object that is copied as a whole. Likewise, an organism is the outcome of development from a single fertilized egg, from a single copy. But a leaf is the product of cell divisions of countless shoot apical meristem cells. These undifferentiated stem cells are the sources of the differentiated plant cells that compose a leaf. There is thus not one source of genetic information that leads to leaf 'copying' (unless one considers the zygote as the source, but this would then reference development of the entire plant and not specifically the leaf). Odum surely knew this, so his choice is perplexing.

I could offer a detailed account of plant mitosis in root, stem, leaf, or flower, and I could apply the information cycle. In mitosis, information is indeed copied, dispersed and tested in information cycles. But for Odum's demonstration I believe that would be redundant. If indeed mitosis represents a distinct 'scale' of information production that is nested within meiosis, or whole organism replication, then all three 'kinds' of information duplication can be found here also (as for each scale of cultural information there exist the three 'kinds' of information duplication, as we will see). What distinguishes the three 'kinds' is the number of passes through the information cycle, and all three cases are found in mitosis as well as meiosis. Individual cell information may be copied once in cell division (one information cycle, Kind II, reproduction). After many cell divisions a leaf is replaced (many information cycles, Kind III, wide sharing). After many more cell divisions over a population of trees, a tree with an unusual leaf may appear (many more information cycles, Kind IV, new information).

In total, mitosis is a 'scale' of biological information duplication that is distinct from whole organism duplication via meiosis in sexual reproduction. The three 'kinds' of information duplication in Odum's Luquillo rainforest demonstration refer to both scales. Odum's demonstration focuses primarily on the larger 'scale' of whole organism reproduction, and this paper will also focus there.

5.4.1. Rainforest

Here is Odum's emergy analysis of leaf 'copying' for comparison with the others. As in the 'reproduction' demonstration above, Odum chooses as the numerator the emergy *per hectare* to support the forest (this is the 'emergy support flow'). For the denominator, however, he chooses the energy in the DNA *of the forest* (not the seedfall) in that hectare (the 'information carrier flow'). This equation also differs from Kind II (Eq. (1)) by calculating the 'emergy support flow' for 1.5 years instead of 1. This is stated to be the replacement time of rainforest leaves. This is not explained further; an explanation may be leaf herbivory. Eq. (4) is the transformity of information in leaf DNA.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{\text{9E14 sej/ha/in leaves}}{\text{1.28E8 J/ha}} = \text{7.03E6 sej/J DNA} \tag{4}$$

Again, Odum's first demonstration of tree leaf replacement is better conceptualized as the result of many cell duplications, the result of many passes through the information cycle. Thus tree leaf replacement is, in fact, an example of 'Kind III', the wide sharing of genetic information, not 'Kind II', reproduction of a single cell, i.e., it is many passes through the information cycle, not one, and it is for the biological scale of mitosis, not meiosis.

5.4.2. Photocopying

This can be compared briefly to the case of photocopying. In contrast, the photocopying example is indeed a demonstration of Kind II, reproduction. If we consider the case of photocopying in slightly more detail than does Odum, we can discover the typical stages of an information cycle. To begin with, photocopying does not occur spontaneously. It requires a motivated person to initiate the process, i.e., to *select* what they wish to copy. Furthermore, copies are made for a reason, that is, once copies are made they are then given *to people*. In general, therefore, it can be stated that in photocopying there is *selection* (Step 2, Fig. 1) (*what* to copy), information *extraction* (3) (in black/white contrast), *copying* (4) (on new paper), and *dispersal* (5) (the sharing of photocopies).

6. Emergy analysis of conversation

My intention in this paper is to produce a parallel or analogous emergy evaluation of conversation. Stated above, the analogous kinds of cultural information might be labeled (I) memory events, (II) conversation, (III) maintaining shared information (culture) in a population of conversations, and (IV) new cultural information. However, as depicted in Fig. 2, memory events (Kind I) are a distinct 'scale' in the hierarchy of production processes of cultural information, analogous to the distinct scale of plant information duplication in mitosis. Thus I will address only Kinds II–IV.

Applying the information cycle to the scale of conversation required careful consideration. What we are *doing* when we speak has been the subject of much social research, and includes unobservable psychological and strategic processes (Goffman, 1959; Bourdieu, 1977; Foucault, 1980). In Abel (submitted for publication-a) this interpretation of conversation was accomplished simultaneously with applications of the information cycle to news media, ritual, education, and other scales of cultural information production (Fig. 3), which by contrast and comparison benefited each of the applications. First, therefore, consider one comparative example of applying the information cycle to cultural information that includes no unobservable processes. In TV News, the sender is the news network that includes newsroom managers and other elites, the 'gatekeepers' (Shoemaker et al., 2001), as the prime *sensors* (1a, Fig. 1) and *selectors* (2) of appropriate news topics, reporters as the *extractors* (3) of information into story form, with, next, the vast technologies and energies of news broadcasting companies as the *copiers* (4) of news stories, copied as they are placed in a format for *broadcast* to viewers, while finally, news stories are *dispersed* (5) as they are routed or channeled to viewers via satellite, cable, or radio transmission, in any case adding additional technologies and energies. In the cases of cultural information produced in ritual, education, academia, or law, an entirely different configuration of information production and technology are required, giving each cultural scale its distinctive message form, and predicted unique transformity (Abel, submitted for publication-a).

In the case of conversation, in contrast, cultural information is transmitted without the need of elaborate technologies and added energies. Only the metabolism of speakers is required. The information cycle may be applied to conversation as follows in this brief account (elaborated in Abel, submitted for publication-a), which considers a wide array of psychological and anthropological theorizing. The *system* (Step 1, Fig. 1) is the site of role-taking, rituals, encounters, etc. The *shared information* (6) is what the self, the agent, brings to an interaction, both explicit and *implicit* cultural knowledge (Fig. 3). A speaker *senses* (1a) the beliefs and expectations of the others and the contribution they can make to the conversation and *selects* (2) input. Idea, intention, affect, and form are *extracted* (3) into the compact form of language in speech sound waves, which are then broadcast (*copied*) (4) to all listeners, who then *disperse* (5).

6.1. Conversation emergy to isolate and extract information in compact form (Kind II)

Recall that the emergy to isolate and extract information into compact form is the emergy of *one* information cycle (Table 1). In a lifecycle of a tree, this was the production and dispersal of seeds (a reproduction cycle). In the case of cultural information, this is one conversation followed by the dispersal of persons to live their lives until their next encounter with same or different people. At that point some of the prior conversation information may be again discussed.

In one conversation cycle, two or more persons exchange speech. The 'emergy support flow' is the emergy support to all the persons in the conversation for the replacement time of the conversation (see Appendix A for conversation data). The 'information carrier flow' is speech energy. Replacement time is the time of conversation, which averages 9 min (Appendix A). For the cultural information, equations are elaborated in Appendix B. Eq. (5) is the transformity of information in conversation speech energy for one conversation.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{\text{2.65E12 sej/conversation time}}{\text{1.28E–3 J/conversation time}} = \text{2.21E15 sej/J} \quad (5)$$

6.2. Conversation emergy for sustaining shared information (Kind III)

'Shared information' implies that there is a population of individuals that are using the information. Most anthropologists would require at least partial 'sharedness' to be a characteristic of any definition of 'culture', though today the ontology of 'culture' is a contentious topic within anthropology (Moore and Sanders, 2006). The anthropological term 'culture' thus refers to this 'kind' of information that requires a population to maintain it within continuous information cycles of selection and renewal.

The previous demonstration followed Odum's rainforest example and avoided the identification of a specific unit (species) of cultural information. Hypothetical cultural 'units' are sometimes addressed as 'memes' in the field of cultural evolution (Dawkins, 1976), and that literature should be the place to look for examples. Surprisingly, however, there is a telling paucity of empirical demonstrations of the evolution of ideas. Instead, we find examples from linguistics (Richerson and Boyd, 2005), technology (projectile points (Lyman and O'Brien, 2003), clothing (Jordan, 2009), bicycles (Lake and Venti, 2009), or cutlery (Riede, 2009)) and behavior (marriage practices (Fortunato and Mace, 2009)). Even the rare paper that claims to be a demonstration of the evolution of cultural practices and *beliefs*, or 'semes' in their terminology (for 'sign' to emphasize the symbolic nature of culture) (Hewlett et al., 2002) is in fact an account of the diffusion of 'practices' only, that is, of behaviors and technologies such as 'house roof material', inheritance practices, or gender specific activities like fishing, boat making, or weaving. This is not a criticism of this research, which is of significant value. But it exposes a fundamental weakness in the quest for an evolutionary study of ideas. Is it possible to identify 'bits of culture', as Maurice Bloch (2000), among many anthropologists, has asked? Problems arise immediately if culture is considered to be an integrated system of ideas (Boas, 1911). However the larger symbolic system of culture is conceived, it remains that drawing boundaries around ideas is a difficult task. A second task just as difficult is demonstrating the emergence and establishment of ideas. The emergence of new technologies leaves a material trace that far exceeds the evidence for idea diffusion or creation.

One problem for anthropology is the failure to recognize the hierarchy of cultural information production, discussed above. Ideas or beliefs, memes, produced in the information cycles of media, education, ritual, etc. are of a different scale from those produced in conversation, they may have a different character, and this could create confusion for analysis. Abel (2011) is an experimental study of the sharing of conversation topics. It thus limits the focus of research to only one scale of culture production, and it offers one approach to operationalizing the unit of ideas as 'conversation topics', with some caveats. Conversation topics have been studied in the fields of marketing and communication (e.g., Duck and Miell, 1986; Goldenberg et al., 2001). The approach in Abel (submitted for publication-a) differs from this research by permitting open-ended labeling of topics and later analysis and reconciling of topics by independent judges from within the conversation community subculture. The caveat I make, and have discussed above, is that 'culture' is not simply the conscious, declarative knowledge that we equate to a conversation topic, but is rather the complex configuration of both implicit and explicit knowledge in human memory (in body and in mind). It should be made clear, therefore, that this paper, as well as Abel (2011) is addressed to the study of cultural information in the information cycle of conversation.

6.2.1. Horizontal sharing

Over some time frame, a great number of conversations are occurring within some spatial expanse (analogous to an ecosystem, such as a campus or small community, though any space is nested within multiple scales). Many specific conversation topics are highly idiosyncratic, and will not recur. But many conversation topics are copied and shared, even to the inclusion of specific details. An approaching election, the opening of a much anticipated movie, or the harsh grading by some professor on a recent exam, these may be conversation topics that are repeated in distinct conversation settings. This I refer to as 'horizontal sharing,' which is 'within-scale' sharing of information by processing it many times through the information cycle. This is analogous to sustaining shared information in a population of rainforest trees.

Unlike the rainforest example, in which tree populations have a long turnover time, we can *witness* the selection of shared conversation topics within a speech community. Cycle times are far shorter and only some conversation topics are repeated. Repeated conversations are taken to be those selected by the speech community. They have a larger spatial and temporal scale than those topics discussed only once. To refer back to the rainforest example, a biological species is that genetic configuration that successfully spreads to a population scale of space and turnover time. Many other genetic configurations may come to exist, but if they do not reproduce into a reasonably sized population they turnover more quickly and their specific genetic information is lost. Again, this occurs on a much larger scale of time and space than Odum uses for his example and so we do not see the lost variety, but it always exists. However in the conversation analogy we see both shared information and that which is lost.

For the case of shared conversation topics, therefore, the 'emergy support flow' is the annual emergy support to sustain one conversation among many within some area (campus) times the replacement time of conversation topics. The total support emergy is divided by the number of sustained topics. The 'information carrier flow' is the carrier flow for *one* shared topic (analogous to one species among 153). Replacement time, however, is the time that a topic is maintained on campus as shared. The average length is two weeks (Appendix A). For a topic to be considered 'shared' it must be discussed several times in a day across campus. Preliminary research suggests that on any day the number of shared specific conversation topics is approximately equal to the number of persons in the population (Abel, 2011). With a campus population of 600, the number of shared conversation topics at any time is 600. Eq. (6) is the transformity of information in the speech energy of a shared conversation topic.

$$\mathrm{Tr} = \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}} = \frac{\text{4.69E15 sej/1 shared topic}}{\text{3.12E–1 J/9 min} \times \text{4 times/day} \times \text{14 days}} = \text{1.50E16 sej/J} \quad (6)$$

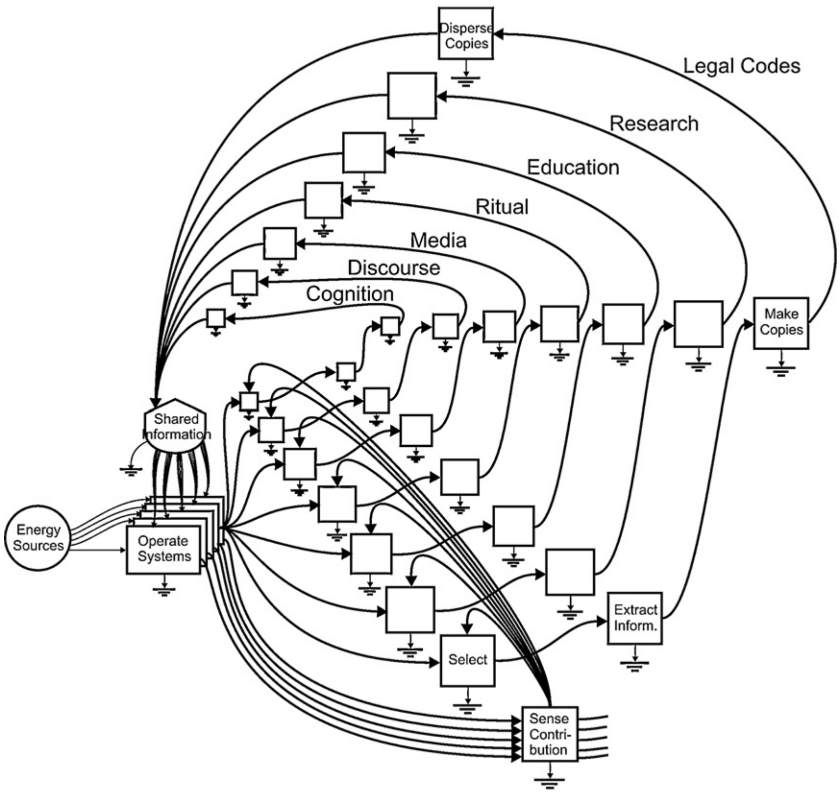

Fig. 4. Hierarchy of information cycles. The hierarchy of Fig. 2 as a nested hierarchy of information cycles that accentuates how each cycle returns objects of information to the same social–ecological context, from which any information may be picked up by any cycle (Abel, submitted for publication-a).

6.2.2. Vertical sharing

The complexity of cultural information is not limited to the horizontal sharing described above. One additional dimension of cultural information organization is vertical sharing through upgrading information to higher quality communication modes. This is depicted in Fig. 4.

Regular conversation that is captured and upgraded through the popular media is widely dispersed, and may have a longer turnover time than conversation topics. Information that is further picked up by ritual, education, research, or law has progressively larger dispersal and longer turnover time. This model of information sharing requires the empirical analysis and comparison of each of these scales. These studies are currently underway (Abel, submitted for publication-b, submitted for publication-c) or planned.

6.3. Conversation emergy to develop useful information (Kind IV)

The emergence of new conversation information is a challenging topic of study. There are two additional considerations. First, in the analogy, the establishment of a new tree species requires wide sharing of genetic information into a reproducing population. For conversation topic information to meet an analogous requirement, they cannot reference specific events that happen once in time, but a slightly more general characterization of a conversation topic can produce many topic matches over an indefinite period of time. The conversation topic literature (e.g., Duck and Miell, 1986) offers topic descriptions that are too abstract, e.g., 'sports', 'romance', but an insightful, analogous demonstration can come from the content analysis of television news (Semetko and Valkenburg, 2000). Here too analysis begins with abstract categories (frames) that include 'conflict', 'morality', 'economics', 'attribution of responsibility', and 'human interest,' but these are also too general to be of value. However, within each category is a series of much more specific characterizations, only slightly above the specificity of an actual event (Table 3).

It is reasonable to make this adjustment from specific event to a slightly more general (schematic) but still specific characterization. Recall that culture is embodied by people in a hierarchy of knowledge. Knowledge in mind has good durability, due to the continuous cycling of human memory (Durrant et al., 2011; Nader and Hardt, 2009) in perhaps information cycles of their own. Most definitions of culture require that it be durable as well as widely shared. Shared conversation topics are thus generally not stored as individual event memories, but as more abstract schemas or cultural models (Holland and Quinn, 1987; Tulving, 1985). These are gradually constructed in a population of individuals over time.

The second additional consideration is that perhaps most of the cultural information that is transmitted in conversation is not *new* ideas or beliefs. According to some cultural evolutionists, imitation or 'social learning', and not individual learning by reinforcement contingencies, is the key process that allows humans to pile innovation upon innovation to create 'cumulative cultural evolution'

Table 3
Attribution of responsibility. These specific characterizations of news story content were found to be very common in Dutch news stories that attribute responsibility for political events to the government or individuals. At this level of generality, many news stories address the same topics. Also, at this level of generality, little *new* or original news content is being produced, but rather prior content is being imitated or 'socially learned' at the scale of TV news.

The story suggests that some level of government has the ability to alleviate the problem
The story suggests that some level of the government is responsible for the issue/problem
The story suggests solution(s) to the problem/issue
The story suggests that an individual (or group of people in society) is responsible for the issue-problem
The story suggests that the problem requires urgent action

(Richerson and Boyd, 2005). If that is the case, then our verbal and behavioral repertoires have been largely the product of cumulative imitations, first from our parents during socialization, and later from other adults and our peers. We learn from others, and when we speak or behave we are reproducing that knowledge, at least in the generalized schematic forms discussed above. We ask ourselves, who did I learn that from, where did I get that idea? If we are honest, whether differential equation, political analysis, or table manners, we commonly have an answer (parent, teacher, or friend), and maybe more than one.

6.3.1. The emergence and wide sharing of new conversation information

Societies possess a great variety of rituals that are recognized as distinct from each other, of education subjects or curricula that are distinct, of distinct scientific principles, legal statutes, and conversation topics. At some point, within each scale of information, distinctive new forms do emerge. While it might be difficult to identify analogous 'speciation' events, they have obviously occurred.

For the conversation empirical demonstration, an unnamed new conversation topic will appear in the United States, ca. 2000. For this demonstration it is necessary to have a frequency of the establishment of new conversation topics. The emergence of new ideas in conversation topics has never been systematically researched, and no empirical data is thus available. For the purpose of demonstrating the procedure and principles involved in calculating the emergy of new useful information, therefore, a different approach will be taken. Using the rainforest results as a model, I will back-calculate the frequency from a reasonable transformity. While obviously not an empirical result, this will be valuable in itself, as a reference for any future empirical work. The result will be a hypothesis regarding the expected frequency of the emergence of new conversation topics in a society, a value never before proposed.

As in Eq. (3), the 'emergy support flow' is the total emergy per shared topic (species) at the appropriate cultural information scale (i.e., conversation) for the time between successive innovations. The population of the United States was 285 million at the time of the emergy analysis (Cohen, 2000). As in the rainforest example (Eq. (3)), the 'information carrier flow' is identical to that used in the last demonstration (Eq. (6)) for sustaining shared information, the carrier energy flow for one shared topic.

Two values will be used for the number of shared topics, and the result will be the calculation of two back-calculated 'new topic frequencies'. The reason for using two values for the 'number of shared topics' is to create a range of results, given that there is no known empirical value for this variable. Loosening the requirement of topic specificity, as discussed above, would result in many more matching topics, and thus fewer distinctly different shared topics. Rather than one shared topic per person, as in Eq. (6), I will propose two values also related to population size, of 1% and 0.1% of the population. It is reasonable that this value relates in some way to population size as populations tend to be more diverse structurally, economically, and ethnically as size increases. The resulting shared topic counts are 2.85 million and 285 thousand topics. If these are judged to be reasonable, then the demonstration is useful.

Conversation emergy related to innovating one new conversation topic is calculated. The equation for the 'per topic emergy support' is as before, taking the total emergy of the focus area and dividing by the number of shared conversation topics (two values) and then multiplied by the 'new topic frequency'. As stated above, the transformity is assigned a value larger than that for Equation 6. A value of approximately two orders of magnitudes is chosen, similar to the substantial jump in rainforest transformities between Kinds III and IV. The transformity value is 1.6E18 sej/J of new topic. The time between innovations is then back-calculated. The number of shared topics at any one time is estimated with the two values, 2.85 million and 285 thousand, under the loosened requirement of topic specificity, discussed above. The yearly emergy flow for the United States was known to be 1.88E25 sej/yr (Cohen, 2000). Equation 7 is the transformity of information in the speech energy of a new conversation topic. The back-calculated frequencies of innovation are 28 days (pop. 2.85 million) and 2.8 days (pop. 285 thousand) (Appendix B).

$$\begin{aligned}\mathrm{Tr} &= \frac{\text{emergy support flow (sej)}}{\text{information carrier flow (J)}}\\ &= \frac{(5.00\text{E}17\ \text{sej/shared topic}) \times (\text{new topic frequency})}{3.12\text{E}{-}1\ \text{J}/9\ \text{min} \times 4\ \text{times/day} \times 14\ \text{days}}\\ &= 1.6\text{E}18\ \text{sej/J}\end{aligned} \tag{7}$$

Some brief comments can be made regarding this result. Days, weeks, between innovations of a new conversation topic within a population of 285 million people, is that reasonable? Again, this refers to the generalized, schematic form of a conversation topic, in which many topics would match each other. Second, under the assumption that social learning is an essential process for 'cumulative cultural evolution', it may be that much, perhaps most, of what we say is indeed re-production of knowledge we have learned from others. As hypotheses for future research, these results are at least worth entertaining. In fact, an added value may be that they force us to consider a more extremely conservative version of cultural evolution, one in which the production of significantly new ideas is perhaps as exceptional as a speciation event.

6.4. Conversation emergy to copy units containing information (Kind I)

The appropriate analogy to this rainforest example would be the single cycling of selected human memory, which is at the smaller *scale* of 'cognitive events' (Fig. 2), not at the *scale* of 'conversation.' In the same way, the single leaf cycle is at the *scale* of leaf reproduction, not at the larger *scale* of whole organism reproduction. I do not offer an analogous 'cultural' model of the *single cycle* process since it has already been demonstrated with reproduction (Kind II) above.

7. Summary

The following Table 4 summarizes the results presented above.

Fig. 5 locates the conversation transformities on a graph of all other human and information transformities that have been calculated (Native culture (Odum, 1996:236), Rainforest (Odum, 1996:222–6), DNA (Odum, 2007:242–3), Education levels (Odum, 1988), LESO Students (Meillaud et al., 2005)). They are larger than most human transformities; even those produced by Abel (2010), which have a range of values (1E5–1E14 sej/J). The conversation values are also compared to two other new information transformities (Kind II, reproduction) from unpublished reports by Abel, one for TV Media (Abel, submitted for publication-c), and another for Education (Abel, submitted for publication-b). The conversation values are less than both.

In every systems diagram produced by Odum that contains a storage of information, the information storage is located furthest to the right, and just beyond a storage for people. This indicates that the transformities for information are expected to be greater than those for people and other organisms. For the empirical studies depicted in Fig. 5, this is generally the case. Another expected relationship is the hierarchy of information, in which cultural information is expected to be of lower transformity than genetic information. These expected relationships reflect the hierarchy principle (Odum's Fifth Law (1996:16)) and the convergence of emergy into fewer objects with longer turnover times and greater

Table 4
Speech energy. All values were calculated above and in Appendix B. Emergy to further share information (IIIb) by upgrading to additional scales (vertical sharing) is included to indicate the importance of this calculation, which is not yet attainable.

Kind	Name	Conversation	Solar emergy	Solar transformity
II	Emergy to isolate and extract information in compact form	Extracting info into speech	2.23E+13	2.21E+15
IIIa	Emergy to *sustain* an information circle, to sustain shared information	Maintain a conversation topic, cultural variant, meme, over many cycles	4.69E+15	1.50E+16
IIIb	Emergy to further share information	Share information at additional cultural *scales*	No value	No value
IV	Emergy to develop new useful information	Develop a new conversation cultural variant	5.0E+17	1.60E+18

feedback effects. They reflect the fact that the carriers of information are exceedingly small flows of energy, in sound waves, print, electromagnetic radiation, DNA, and others. And they reflect the fact that cultural information is modified and produced more rapidly (with shorter turnover time) than genetic information in successful mutation and in speciation. In general, therefore, the expected transformity relationship is: people < culture < DNA.

The cultural information transformities calculated for this paper meet these expectations in some cases and not in others. As expected, the conversation transformities are larger than all human transformities in Fig. 5. Furthermore, the Kind II value is lower than the cultural transformities for TV Media and Education, which is also expected by the hierarchy of cultural information scales in Fig. 4. Last, they are smaller than many of the information transformities. However, they are all larger than the information transformities for native culture storage, last book copy, cultural information storage PNG (Papua New Guinea), maintaining a tree species, and even human genetic flow. Furthermore, the transformity for creating a new conversation topic is even larger than human DNA gene information. Creating a new education or media topic would be larger still. Finally, the larger scales in the cultural information hierarchy depicted in Fig. 4 (research, legal codes), are expected to have even larger transformities for each of the information modes. Are these values too high? Does the prior research on information underestimate transformity values due to some systematic difference such as the use of DNA energy as the information carrier? Does this current research overestimate transformities, due again to some systematic flaw? These issues can only be addressed by additional emergy studies of information . This area has lagged far behind the analysis of other energy transformation processes. Further empirical research is imperative.

8. Open issues

In none of his information cycle demonstrations does Odum calculate emergy transformities for all the steps in the information cycle. He is interested in the largest transformity, which he expects to be at the 'make copies' step. Thus the *information carrier flow* energies that he must calculate are simply the energy contents of DNA in seed or egg. In the case of conversation, the 'make copies' *carrier flow* refers only to speech energy. In contrast, the *information carrier flow* in the 'dispersal' step of a rainforest cycle would need to include the wind, rain, or animal energy that contributes to dispersal. In the conversation case, it would include the energy of walking, riding, etc. In comparing 'dispersal' to 'make copies' steps, therefore, for both cases, carrier energies would be higher, and transformities would thus be significantly lower.

Another important issue not addressed is the fact that for each of these analyses only one human transformity was used in

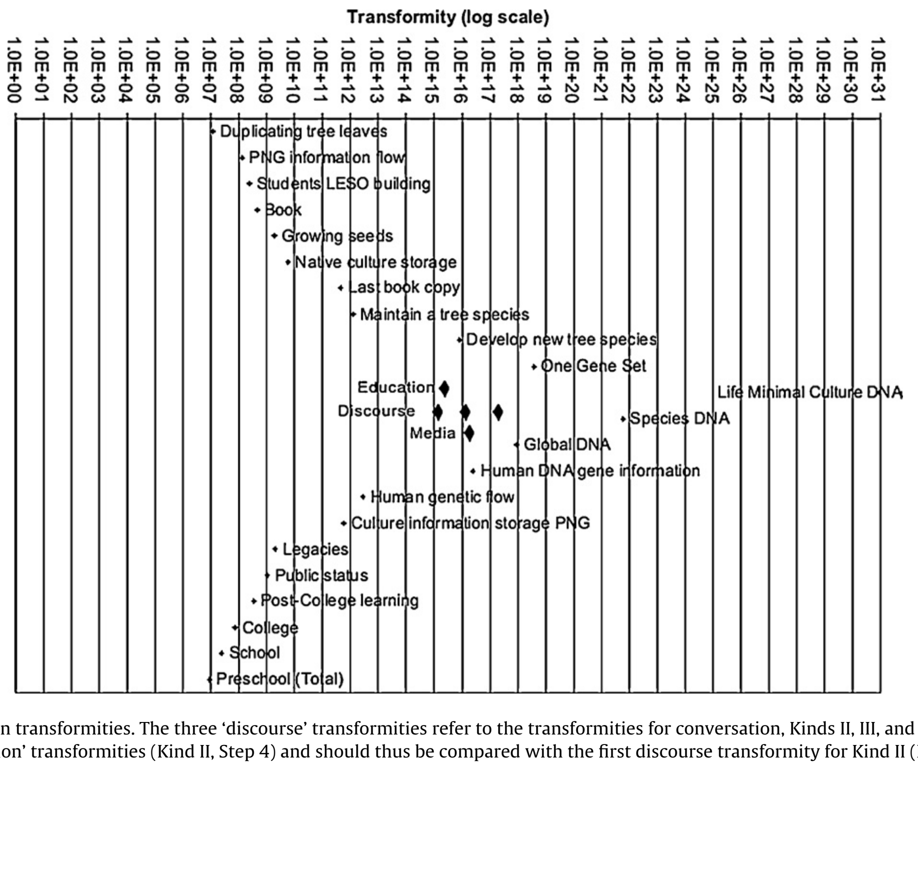

Fig. 5. People and information transformities. The three 'discourse' transformities refer to the transformities for conversation, Kinds II, III, and IV. The education and media transformities are 'reproduction' transformities (Kind II, Step 4) and should thus be compared with the first discourse transformity for Kind II (Eq. (5)).

calculating the *emergy support flows*. As per Abel (2010) and Odum (1996), there is a wide range of human transformities that reflects multiple scales of humans or households, not found in other species. Applying each of the human transformities to the calculation of 'emergy support flow' would create a related range of information transformities. The conversation transformities calculated in this paper, therefore, should be understood to be only one point in that range.

9. Conclusions

The information cycle is a powerful conceptual model for theorizing information of all types, and culture in particular. Culture, like all storages or concentrations in the universe, requires energy for maintenance against Second Law depreciation. The information cycle reminds us of that necessity, and provides a schematic account of the essential steps in that renewal process. Both the structure of the information cycle, with its copying and testing, and the fact of its relentless cycling force a reconceptualization of the culture concept.

Because cultural information is tested and 'selected' with each cycle, cultural information must be in character fundamentally instrumental. The difficulty for the social sciences remains the demonstration of that instrumentality, which need be conceived, but seldom if ever is, within a multi-scaled world that is structured by self-organization. Simple single-scale causal-chain arguments are always incomplete, or worse at times, misleading. The functions of cultural information need be found within the complex nesting of social, political, and ultimately ecological contexts, structured by energy self-organization.

The requirement that information be cycled endlessly in its maintenance is a second fundamental conceptual breakthrough of even greater originality than the first. The social sciences have not looked for the processes by which information is cycled because they did not recognize the need for that cycling. Culture once created was taken for granted. The information cycle draws us to that requisite process; it incites us to discover and explore its nature at every encounter with information, and to ask how each particular realization of the cycle might affect the character of the information.

Finally, the information cycle when understood as linked energy transformation processes opens the door to emergy analysis. Emergy alerts us to the fact that the construction of cultural information occurs in transformation 'processes' that have essential emergy inputs. The quantification of emergy inputs to information processes leads to the calculation of transformities. Transformities make possible the 'location' of cultural information relative to other information forms (Fig. 5) and to the many environmental, economic, and human processes within which it is nested. Furthermore, emergy provides a methodology for disentangling the empirically distinct 'scales' of cultural information (Figs. 2 and 4). The emergy evaluation of information allows for the empirical demonstration of both cultural hierarchy and the location of culture within hierarchies of environment–economy–people–culture.

Three transformities were produced in this paper for the information in conversation, labeled Kinds II, III, and IV (Table 4). Their difficulty in calculation increased with Kind. At this stage in the infancy of the emergy analysis of information, it is recommended that Kind II analyses should be the goal of research. Emergy analyses would be thus one occurrence of the information cycle, that of the duplication of information, the essential process for the maintenance of information against Second Law depreciation. Furthermore, as Odum has done, it is recommended that the analysis be conducted at Step 4, *copying* of information. With future analyses focused to this Kind and Step, it should be possible to produce easily comparable results. Certainly additional analyses for Kinds III and IV may be performed, but it is perhaps of greater value at this point to produce a baseline of cultural emergy analyses.

The time has come for developing guidelines for applying Odum's rainforest information cycle demonstration to the analysis of cultural information, if the study of culture within nature is to be advanced. This paper provides those guidelines. This has required a detailed deconstruction of Odum's rainforest demonstration, followed by an analogous assembly of a parallel cultural example. While the empirical production of cultural transformities has required a number of innovative assumptions that may be challenged, the greater value of this exercise comes from the demonstration of required concepts and methods. These methods have been exhaustively considered and weighed in the process of applying them to empirical study. Still, the field is new and unexplored and these demonstrations may not be the final models for emergy analyses of information. It is, however, hoped that the examples presented here represent a reasonable and instructive first blueprint for the emergy study of cultural information.

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Appendix A. Conversation behavior

See Table A1.

Appendix B. Emergy analyses

B.1. Conversation emergy (Kind II) (Eq. (5))

Emergy support flow = emergy support to2.5 persons × conversation time (9 min)

$$\begin{aligned}\text{Emergy} &= (\text{daily metabolism}) \times (2.5\ \ \text{people})\\ &\times (\text{average human transformity}) = 2500\,\text{kcal/day}\\ &\times 4186\,\text{J/kcal} \times 2.5\,\text{people} \times 7.3\text{E}7\,\text{sej/J}\\ &= 2.23\text{E}13\,\text{sej for}2.5\,\text{people for}\,9\ \text{min}\end{aligned}$$

Information carrier flow

Energy of *speech carrier waves* (information carrier) for 2 min conversation

$$\begin{aligned}\text{Energy} &= (\text{speech energy}) \times (\text{conversation length}) = 1\text{E}{-}5\,\text{J/s}\\ &\times 9\ \text{min} \times 60\,\text{s/min} = 5.57\text{E}{-}3\,\text{J}\end{aligned}$$

$$\text{Transformity} = 2.23\text{E}13\,\text{sej}/5.57\text{E}{-}3\text{J} = 2.21\text{E}15\,\text{sej/J}$$

B.2. Conversation emergy (Kind III) (Eq. (6))

Emergy support flow = emergy to support one sustained conversation among many within some area (campus), i.e., all support emergy divided by the number of *shared* topics (600 at any one time, see Appendix A) (*Note*: *all* emergy goes to conversation

Table A1
Conversation behavior. Measurements and estimations of conversation behavior. Much of this data was collected as part of a conversation experiment (Abel, 2011), but is not yet published. Use of this preliminary data and calculations will allow the demonstration of methods for calculating conversation emergy, which at this point is the aim of this paper.

Variable	Value	Units
Avg. number of people in conversation=	2.5	People[a]
Avg. time in conversation=	130	Minutes/day[b]
Average conversation length=	9	Minutes/conversation[a]
Average number of conversations=	14	Conv/person/day[c]
Average length of time a topic is shared=	14	Days[a]
Average repetitions of a shared conversation topic per day	4	Topic repetitions per day[d]
Average number of shared topics across campus at any one time	600	Topics[e]
Average number of shared topics in the US at any one time	285,000	
	2,850,000	Topics[f]

[a] Abel (2011).
[b] Mehl and Pennebaker (2003), half the estimate for US students based on observations of Taiwan students.
[c] Calculated from note 2 and 3.
[d] Extrapolation from Abel (2011).
[e] Following observation of relationship of 1 shared specific topic per person (600 on campus).
[f] Loosening the requirement of topic specificity (in text), estimate 1 shared general topic per 1% and 0.1% of the population)).

'scale'). Annual campus emergy calculated in Abel (submitted for publication-b).

$$\begin{aligned}\text{Emergy} &= (\text{annual campus emergy})\\ &\quad\times(\text{duration fraction of 2 weeks})/(\#\text{shared topics})\\ &= 7.32\text{E}19\ \text{sej/yr}\times(2/52)/600\ \text{topics}\\ &= 4.69\text{E}15\ \text{sej/1 shared topic for 2 weeks}\end{aligned}$$

Information carrier flow
Energy of *speech carrier waves* (information carrier) for 2 min conversation, 4 times a day, for 2 weeks

$$\begin{aligned}\text{Energy} &= (\text{speech energy})\times(\text{conversation length})\\ &\quad\times(\text{shared duration}) = 1\text{E}{-}5\,\text{J/s}\times 9\ \text{min}\times 60\ \text{s/min}\\ &\quad\times 4\ \text{per day}\times 14\ \text{days} = 3.12\text{E}{-}1\,\text{J}\end{aligned}$$

$$\text{Transformity} = 4.69\text{E}156\ \text{sej}/3.12\text{E}{-}1\,\text{J} = 1.50\text{E}16\ \text{sej/J}$$

B.3. Conversation emergy (Kind IV) (Eq. (7))

Emergy support flow = emergy to support one sustained conversation among many within some area (Unites States, ca. 2000), i.e., all support emergy divided by the number of *shared* topics. (*Note*: *all* emergy goes to conversation 'scale'). For the back-calculation (see text), the given transformity is 1.6E18 sej/J. With an 'information carrier flow' of 3.12E−1 J/topic, the per topic emergy support flow is:

$$\begin{aligned}&= 1.60\text{E}18\ \text{sej/J}\times 3.12\text{E}{-}1\ \text{J/topic}\\ &= 5.00\text{E}17\ \text{sej/topic}\end{aligned}$$

The two frequencies of innovation will be back-calculated from this per topic 'emergy support flow'.

$$\begin{aligned}\text{Per topic emergy support} &= (\text{annual country emergy})/(\#\text{shared topics})\\ &\quad\times\text{new topic frequency}\end{aligned}$$

Shared topics – 285,000 topics

$$5.00\text{E}17\ \text{sej/topic} = 1.88\text{E}25\ \text{sej/yr}/2.85\text{E}5\ \text{shared topics}\times(\text{new topic frequency})$$
$$\text{New topic frequency} = 2.8\ \text{days}$$

Shared topics – 2,850,000 topics

$$5.00\text{E}17\ \text{sej/topic} = 1.88\text{E}25\ \text{sej/yr}/2.85\text{E}6\ \text{shared topics}\times(\text{new topic frequency})$$
$$\text{New topic frequency} = 28\ \text{days}$$

Information carrier flow
Energy of *speech carrier waves* (information carrier) for 9 min conversation, 4 times a day, for 2 weeks (same as #3)

$$\begin{aligned}\text{Energy} &= (\text{speech energy})\times(\text{conversation length})\\ &\quad\times(\text{shared duration}) = 1\text{E}{-}5\,\text{J/s}\times 9\ \text{min}\times 60\ \text{s/min}\\ &\quad\times 4\ \text{per day}\times 14\ \text{days} = 3.12\text{E}{-}1\,\text{J}\end{aligned}$$

$$\text{Transformity} = 5.0\text{E}17\ \text{sej}/3.12\text{E}{-}1\,\text{J} = 1.6\text{E}18\ \text{sej/J}$$

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