Exploration of Structural and Kinetic Components of Physical Information †

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Abstract: As Wiener asserted, information is information, not matter, not energy. Physical aspects of information are deeply grounded in energy transformation processes. Adopting an evolutionary perspective, it is demonstrated that there are two complementary informative influences on energy transformation. To do this, we use a simple model of an idealized monochord instrument. This allows modeling information contained in the kinetics of the oscillating string as both (a) generated by the structure of the instrument, and (b) generating non-arbitrary motion structures in sensible receiving configurations that are similar in scale, geometry, and material properties.

Keywords: information; energy; model; structure; motion

This text presents only a certain aspect of the much larger exploration of information, which is physically effective or “meaningful” in an evolutionary context. Inside the larger research context of the project Evolution of Information processing Systems, in the presentation we address the hypothesis that there are actually two types of physical information with distinctly different dynamics to consider. Assuming a connection between the basic grounding of the conservative character of energy-transforming systems in physics, which is a stationary relation between the two forms of energy (E_{kin} and E_{pot}) in Newtonian equations of motion [1] and information viewed as a physical quality for storage and selection on processes, sounds reasonable. Physical information might be behind the basic physical differentiability of the kinetic and the potential form of energy in stable systems with energy transformation. Nevertheless, information cannot be quantified by kinetic respectively potential energy. Information is not energy [2], information acts on energy. The reasons for not adopting the original definitions for the two types of physical information originally proposed in reference [3] have been discussed in an earlier publication, and a revised definition was proposed [4].

The difficult concept of information [5–10] gains a lot of logical consistency when viewed as developing in an evolving context (see Figure 1). More than that, the retraceability through a recursively developed model of the evolutionary process increases plasticity. From the initial basis analogy of kinetic and structural types of information to potential and kinetic energy in conservative systems (as inspired by [3]), an intuition for the connectedness of the stability of systems and the related evolvability of structurally dispositioned properties on reciprocal relationships in kinetic and structural information arises. The negative reductionist flavor that suggests simplification is mitigated when the respective novelty compared to earlier selective regimes and the sheer amount of evolutionary steps that must have been necessary in-between become vivid in relation to the deeply rooted physical basis. Recursivity, i.e., the presence of the older selective criteria in the newer ones, is never completely lost in the model, compensating for the appearance of reductionism.
Bateson’s iconic sentence is often quoted when a definition for the meaning of information in context is searched for.

“What we mean by information—the elementary unit of information—is a difference which makes a difference, and it is able to make a difference because the neural pathways along which it travels and is continually transformed are themselves provided with energy.” [11]

This is clearly a description of information limited to human communication and neuronal language processing. The formulation “elementary unit of information” already hints at a broader applicability of the idea for units of stability in their environment.

For an examination of the concept in a less specialized, more diverse evolutionary context, the idea expressed in the quote serves very well as a starter. Even for physical systems, information viewed as “a difference that makes a difference” leads to two important and mutually corresponding questions:

• How does a difference arise in physical structures (so that it could be sent)?
• How can a difference be made in physical structures (indicating that receiving had effect)?

Energy input alone cannot inform a system, triggering a difference in its configuration that subsequently leads to new ways of interacting with its environment that could make a difference, if there is nothing left from the original system to which the difference can be related. The effect of received information thus needs to be storable, and the difference that is made due to the change of form somewhere in the receiving system needs to be capable of influencing selective processes in the receiving system (i.e., differences made to the system’s acting inside its environment). Irreversible change of form and maybe subsequently of structurally dispositioned properties is a way of storing impact effects that occur in materials. Motions also can store, i.e., perpetuate impacts and spatio-temporal patterns of impacts, and they can also transport them. Materials and motions thus can both store structures, i.e., patterns that affect energy flows in favor of their maintenance. Material- and motion structures both are capable of selectively influencing processes. Structure stored in motion or stored materially represents as well as influences the selectivity in its environment. This will be called here the informational perspective. The basic idea is that selectivity and storage are functions that can be expressed in two physically different ways, and that this difference is due to two different methods of structure formation and consequently structure maintenance in physics. Storage and selectivity criteria have evolved based on fundamental physical information and unlocked a wealth of new possibilities, as can be seen in present day structures.
Motion structures are structures instantiated in the motion of mutually largely independent but correlated units (a medium) and observable as motion-pattern (like interchanging cusps and troughs, respectively; high and low densities; and more complicated repetitive patterns). Ideally, the medium consists of mutually independent charge carrying (massive) particles inside a potential so that a maximum amount of degrees of freedom is available for mapping a nonrandom translation, rotation, oscillation, or mixture of interfering motions. Kinetic information (I\textsubscript{kin}) basically is what gives a form to kinetic energy, a structure to motion. Important for interference to be possible is spatial and or temporal correlation between motion vectors; both are strongly influenced by potentials and the motion history.

Configuration structures are structures instantiated in mutually dependent interacting and energy-of-certain pattern exchanging (i.e., I\textsubscript{struc} “using”) units that maintain a material configuration with invariant material properties at a state of either rest or largely retarded change. Structural information (I\textsubscript{struc}) is what generates characteristic configuration structures, which establish and alter locally available potential energy due to invariance in mass and charge and their spatial distribution. Configurations can best be expressed as a “list” of possible energies inside a system, including the total of the system molecule’s microconfigurations plus the energy differences between those possible configurations that maintain the organizational closure that enables the continued availability of potentials as sources of the characterizing potential energy.

1. The musical monochord instrument is generating kinetic information

In the presentation, the visualization of the reciprocal relationship between information kinetically transported in excited modes of media and information structurally represented by configuration is in focus. This relationship is demonstrated using the simple model of an idealized monochord instrument. Such an instrument was used by the Pythagorean School e.g., [12] to explore the numerical relationships between two-note harmonies. It consists of a single string, fixed at both ends, that is stretched over a moveable bridge. The bridge can be adjusted to divide the fundamental length of the string into parts of certain mutual proportions. If the undivided string is plucked and allowed to vibrate over the whole of its length, the tone that can be heard is called first or more precisely the fundamental harmonic of the instrument. This basic frequency is a result of the material qualities of the string and the resonating body (i.e., all parts of the instrument that are not the string but that constrain and support the string’s oscillation, selectively amplifying and dampening frequencies). The ear senses the fundamental frequency as the lowest pitch the instrument generates. Proportional partitioning of the string generates higher frequency sounds, more generally frequencies that are odd or even (integer) multiples of the fundamental frequency. When the fundamental length string is divided and excited to vibrate at frequencies that are 2, 3, 4, ..., \(n\) times multiples of the frequency of the full length vibration, the generated tones form the harmonics of the overtone series.

2. The kinetic information in the sounds generated by the monochord is received in the acoustic sensory system

Kinetic information of the sound waves excited in the air surrounding the monochord is received by the (human) auditory sensory system, which has structural information that favors reception, i.e., possesses structurally dispositioned sensitivity for this kinetic structure.

There is similarity between the monochord string and the human auditory organ with respect to excitable frequencies (see Figure 2). The size and stiffness of the basilar membrane of the cochlea enforce frequency-selective localization and dispersion of surface traveling waves modeling incoming sound waves. The vibrations cause a movement of the cochlear fluids and the cochlear partitions, displacing the fluid to the round window. The cochlear traveling wave travels from base to apex, where the round window is located. The relationship between the actual sound pressure and velocity of particles in the cochlear fluid is a medium property analogous to the refractive index, but the cochlea “medium” has very inhomogeneously distributed properties of stiffness, while the traveling wave induces a likewise inhomogeneous distribution of mass. The organ of Corti, which is
in close contact with the basilar membrane, gets locally excited at the amplitude maximum of the basilar membrane vibration and translates the excitation into a neuronal signal.

Figure 2. Human middle- and inner ear. Uncoiled cochlea with focus on the basilar membrane and the location of some of its excitable frequencies. The initial mechanical analysis in the ear is subsequently improved and sharpened by a data analysis network of neurons in the brain. Figure composed using original work by Cenveo [13].

3. *Istruc* and *Icon* of motion- and configuration structures from an evolutionary perspective

Applying the evolutionary view on information dynamics in the monochord example and on the receivers and media excitable by its acoustic (temporal) frequencies, several layers of sequentially established information processing and using systems can be distinguished. The layer deepest down is the dynamics and selective mechanisms of physical environments. As has been said, the recursive model of nested environments emphasizes that the deeper (i.e., evolved earlier in the evolutionary process) layers down to the putative “core of the onion” always have to be kept in mind when thinking about selective dynamics in layers nearer to the surface.

Structural information defines the components’ forms and geometries as well as their mutual spatial relationships in the monochord. Further, it is the disposition for excitable types of kinetic energies (e.g., wave forms and cycles inside a given frequency bandwidth and with amplitude inside a certain scale) and for structurally dispositioned sensitivity to oscillate in resonance to externally exciting kinetic information with fitting frequencies. In the monochord, excitable energies comprise continuous kinetic energies that are compatible with the maintenance of the monochord and discrete microscopic chemical components’ energy levels. Additionally, macroscopic discrete kinetic oscillation frequencies can be generated selectively and comparatively straightforwardly. The latter is possible only in very few macroscopic structures, so the monochord structure has been culturally selected for this function of its structural dispositions.

Motions where a description using *Ikon* makes sense are special in that their structure is not thermal but is a representation of (largely elastic) influences through interaction forces or interference modulated by scalar potentials. These motions’ unique factor is the knowledge information that one can extract about their development. This knowledge could be extracted due to periodicity or through modeling the predicted state of the moving object at the final position relative to its initial state. Periodicity is the case in all motions that are described by some kind of wave function. Then, the complex wave form of a signal is treated as path that is closed onto itself into a loop, enabling approximation of the form by Fourier transformation. In other cases, knowledge could be extracted through modeling the predicted state of the moving object at the final position relative to its initial state [1] and references on the Principle of Stationary Action therein. When it is known that the moving object can be seen as an individual body that will maintain stability without dissipating energy to such a degree as to becoming unrecognizable by the observer, stationary relationship in the Lagrangian can be assumed. The two motion types in which stationary action
appears to be the key to describing the course of energy transformations are therefore those where science has knowledge information describable as mathematical predictability. First is the Newtonian type of “classical” motion, where stationary action is usually described by applying the calculus of variations on the time integral of $E_{\text{kin}}$ minus $E_{\text{pot}}$ (also known under the name Lagrangian) over a defined path, ignoring dissipation to a large degree, because it is possible.

The second is the type described by equations of fluid motion up to the type described by quantum mechanical wave functions, where not a single stable configuration is moving, but where the motion structure that has been excited inside a field is being followed in time. Motion can become constrained following the Principle of Stationary (respectively, least c.f. [1]) Action, if energy to overcome constraining is (locally and/or temporally) or is (artificially) made unavailable [1]. Nevertheless, it is important to keep in mind that the 2nd Law of Thermodynamics always holds: whenever a constraint to reaching a flatter energy level distribution (…) is removed, entropy will increase [1].

It will become very interesting for understanding information use in evolutionary younger selective environments when the basic physical dynamics will be better understood than is currently the case. However, physics has already discovered many of the fascinating field potential dynamics, more than is known and easily available in literature accessible to information philosophers or even biologists. A series of papers is thus planned by the author in which some of the less known deeper layer physical mechanisms will be explored in their possible relevance for modeling dynamics of kinetic and structural information in general and their appropriateness as $\text{Gedankenmodell}$ for understanding higher level dynamics of information use that are at the moment hidden or underestimated.

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