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ABSTRACT

A free energy principle (FEP) has been recently advanced, giving a mathematical framework on how the brain of adaptive systems or organisms enable them to carry out learning and perception. The FEP states that the collection of sensory states that the brain encounters seems to follow a natural tendency to resist disorder, or maintain a low level of entropy (Friston, 2012). Friston (2012) posits that any adaptive change in the brain, i.e., learning, involves minimization of its neuronal energy. This paper applies the FEP theory to Wallas' four-stage creative process to explain how creativity in a human individual operates.

Keywords: Creativity, Free energy principle, Free energy cycle, Entropy, Surprise, Helmholtz machine

INTRODUCTION

On one hand, a free energy principle (FEP) has been advanced, giving a mathematical framework for how the brain of adaptive systems or organisms enable them to carry out learning and perception. The FEP states that the brain's collection of sensory states seems to follow a natural tendency to resist disorder, or maintain a low level of entropy (Friston, 2012). By keeping the "surprise" of sensory states low, entropy is consequently kept low as well, as the latter is simply the average value of the sensory states over infinite time. Friston concludes that "…any biological system…should have, encoded in its internal (macroscopic) states, a *representation of causal structure* (italics mine) in its external milieu: and should act to fulfill predictions based on that representation. Put simply, biological systems entail a model of their environment and act to maximize the evidence for that model and, implicitly, their own existence." (Friston, 2012) Indeed, learning comes about when the brain minimizes "surprise" by avoiding sampling events that are outside the aforementioned (internal) representation of causal structure with which it may likely be unfamiliar. The FEP model is anchored on neurological activities of the brain which are independent of the consciousness of the organism possessing the brain, i.e., the brain as a learning organism acts by and for itself. On the other hand, the English psychologist Graham Wallas outlined in his 1926 book "The Art of Thought" the four stages of the creativity process, namely preparation, incubation, illumination, and verification. One element that differentiates one stage from the other is the presence or absence of a state of consciousness of an individual at each stage. The first and last stages are *conscious* activities of an individual possessing an organic brain trying to produce a new solution, knowledge, or invention at the end of the creative process. The middle two stages, however, are purely *unconscious* activities of the organic brain and works independently of the participation of the individual possessing it. The more important quality of this creativity model is "…the interplay of the stages and the fact that none of them exists in isolation from the rest, for the mechanism of creativity is a complex machine of innumerable, perpetually moving parts" (Popova, 2013).

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Wallas' Four-Stage Creative Process

In his 1926 book "The Art of Thought", English social psychologist and educationalist Graham Wallas outlined four stages of the creative process, namely *preparation, incubation, illumination,* and lastly, *verification*. The element that differentiates one stage from the other is the presence or absence of the active use of consciousness at each stage. The first stage of *preparation* involves a focused direction of the brain by the conscious person in gathering information that will later produce a new idea or a resolution to a problem. This stage involves a conscious state that requires obtaining all requisite information, investigating the circumstances of the issue, and logically assessing the value of the information gathered. While the person perceives and collects relevant data from his environment, the brain stores every conscious information into its memory. The next two stages of incubation and illumination are primarily the consequences of unconscious processing. In incubation, the brain is somehow left to process and organize all the plethora of information that was acquired consciously after some period of time. Incubation is an unconscious process where the concept of combinatorial play or scheme takes place (Boden, 1994; Popova, 2013). Wallas notes that, due to its unconscious nature, incubation may take one of two forms, either by abstaining from the problem at hand and consciously working on another problem, or by avoiding conscious mental work towards the problem, e.g., sleep. At the illumination stage, every creative resource that the brain has sorted, assessed, and organized connect, and relevant but seemingly disparate parts give birth to a new idea, or a new approach to a solution. It is the stage where related bits of information come and link together to become flashes of insight. Like the previous stage, it is a wholly unconscious process, and generally cannot be consciously forced to conception. It is here that the major idea in a problem-solving or inventive process arrives and enables the solver or inventor to finally resolve the issue at hand. At the last stage of the creative process, verification, the creative process once again switches to an active conscious state, and is the point where the potential idea or solution is tested and confirmed. This stage requires the testing of a solution to a problem, making sure that all the conditions of the problem are satisfied. It is a conscious step in which the solver ascertains the logical coherence of the creative process, and affirms that the solution satisfies the requirements of scientific, literary, or artistic method. Wallas borrowed Poincare's approach of distinguishing the four "phases" of creativity, and was the one who gave the names for each of the stages in the process (Boden, 1994).The prominent French mathematician Jacques Hadamard was also inspired by Poincare's fourfold classification and constructed a list that was virtually equivalent to Wallas': conscious study, unconscious maturing, insight or illumination, and finally, synthesis (Barzun, 1946). The presence of the four stages always seems to be detectable in any creative process. Indeed, there are many examples in the history of science where its practitioners would temporarily forego solving an intractable problem but later arrive at a solution after a flash of ingenious insight. As an example of the unconscious activities of incubation and illumination after preparation, the great French mathematician Henri Poincare wrote in his book *The Foundations of Science: Science and Hypothesis, the Value of Science, Science and Method:*

"Most striking at first is this appearance of sudden illumination, a manifest sign of long, unconscious prior work. The role of this unconscious work in mathematical invention appears to me incontestable, and traces of it would be found in other cases where it is less evident. Often when one works at a hard question, nothing is accomplished at the first attack. Then one takes a rest, longer or shorter, and sits down anew to the work. During the first half-hour, as before, nothing is found, and then all of a sudden the decisive idea presents itself to the mind. It might be said that the unconscious work has been more fruitful because it has been interrupted and the rest has given back to the mind its force and freshness" (Popova, 2013). Another example is the discovery of quaternions in 1843 by William Rowan Hamilton. He related his discovery to his son through one of his letters as follows:

"But on the 16th day of the same month – which happened to be a Monday, and a Council day of the Royal Irish Academy – I was walking in to attend and preside, and your mother was walking with me, along the Royal Canal, to which she had perhaps driven; and although she talked with me now and then, yet an under-current of thought was going on in my mind, which gave at last a result, whereof it is not too much to say that I felt at once the importance. An electric circuit seemed to close; and a spark flashed forth, the herald (as I foresaw, immediately) of many long years to come of definitely directed thought and work, by myself if spared, and at all events on the part of others, if I should even be allowed to live long enough distinctly to communicate the discovery. Nor could I resist the impulse – unphilosophical as it may have been – to cut with a knife on a stone of Brougham Bridge, as we passed it, the fundamental formula with the symbols, i, j, k; namely,

$$i^2 = j^2 = k^2 = ijk = -1$$

which contains the Solution of the Problem, but of course, as an inscription, has long since moldered away. A more durable notice remains, however, on the Council Books of the Academy for that day (October 16th, 1843), which records the fact, that I then asked for and obtained leave to read a Paper on Quaternion's, at the First General Meeting of the session: which reading took place accordingly, on Monday the 13th of the November following." (Wilkins)

It is interesting to note that the time from incubation to the illumination for this discovery was 15 years!

Active State and Internal State

It would be noteworthy to consider how the brain collects sensory signals or sensory inputs from its environment. The assumption in this paper is that human beings are considered as Helmholtz machines, i.e., they are adaptive entities endowed with an organic brain that follows the Helmholtz unconscious inference principle. The creative process is thus characterized by stages each of which may entail the presence or absence of active states ("conscious") and internal states ("unconscious"). The brain gathers information in the form of sensory signals that are then stored in its memory. The sensory signals become the components of vectors in an infinite-dimensional vector space the measurements of which are culled from the environment the organic brain is interacting.

The Free Energy Principle

The free energy principle hinges on the concept of free energy, a quantity borrowed from information theory, which acts as an upper bound for the amount of entropy that sampling data possess. The free energy principle states that the neuronal free energy *F* is an upper bound for the "surprise" of a sensory signal, quantitatively defined as $-lnp(y|m)$, where$p(y|m)$gives the conditional probability density of all possible sensory inputs or signals received by the brain from its external environment based on a generative model m .

For example, the sensory signal $y(t)$corresponding to the event of a person running at the speed of sound would have a high value of surprise, while the sensory signal corresponding to the event of the sun rising in the morning would have very low surprise, presumably close to zero. An improbable event is therefore "surprising", while mundane, day-to-day occurrences are not.

Entropy is then defined as the average surprise of events sampled from a probability distribution or density over all time (Friston, 2009). That is,

Entropy = $\lim_{T\to\infty} \int_0^T -lnp(y|m)dt$

The neuronal free energy *F* is defined as the sum of the Kullback – Leibler divergence between the conditional probability distribution and recognition probability distribution, and the "surprise" (Friston, 2009). The recognition pdf$q(\vartheta, \mu)$ gives a representation of the causes of the sensory signals.

F = Kullback-Leibler divergence + Surprise
= $D\big(q(\vartheta, \mu)||p(\vartheta|y)\big) - ln\, p(y|m)$

Here, *m* denotes the generative model for the system, μ is the internal state of the brain, $y(t)$is the sensory signal or input, ϑ is its causes, and $q(\vartheta, \mu)$is the recognition density of causesϑ.The Kullback-Leibler divergence$D\big(q(\vartheta, \mu)||p(\vartheta|y)\big)$is the positive measure of the difference between two probability distributions, and indicates how much information is lost when$p(\vartheta|y)$is approximated by $q(\vartheta, \mu)$.

The neuronal energy *F* is minimized when the approximation $q(\vartheta, \mu)$ becomes close to the conditional distribution $p(\vartheta|y)$, making the divergence close to zero. In an ideal situation, the two distributions become equal, in which case free energy is minimized, and would then render free energy equal to the surprise. Learning occurs when the surprise is continually decreased by the brain viavariational Bayesian means to reach a minimum (Friston, 2012), thereby decreasing the difference between the distributions $q(\vartheta, \mu)$and $p(\vartheta \mid y)$.This minimization is made possible by the continual "update" of the conditional distribution $p(y|m)$ every time the brain interfaces with its environment ("active states"). This implies that the brain is a Bayes optimal system which follows the Helmholtz principle of unconscious inference.

The Free Energy Cycle

The free energy cycle is a process which has an expression that is similar to the conservation of energy. The free energy cycle posits that the amount of a person's neuronal energy has the same value$F$ at every moment of its interaction with the environment. This is the same quantity introduced in the preceding section that was defined as the sum of the K – L divergence and the surprise. Itis similar to the physical fact that the total energy of an object in motion is the sum of its kinetic and potential energies, but whose value remains constant throughout the period of motion. The free energy cycle has four phases, and each phase has an equivalence at every stage of Wallas' four-stage creative process.

The four phases are as follows:

I. **External State - Environment.** This is an active state of the brain, and is the phase in which the environment around the brain changes. The environment is the source of sensory signals, and its changes are characterized by equations of motion $\frac{d\vartheta}{dt} = f(\vartheta, \alpha)$. The development of the conditional pdf $p(y, \vartheta)$ occurs at this phase.
II. **Internal State – Storage.** At this phase the brain processes collected sensory signals and stores them in memory afterwards. This process is unconscious, and is the point in the cycle where the recognition probability density $q(\vartheta, \mu)$ is developed. The recognition probability densityis in general different from the conditional pdf, and the former is always an approximation to the latter, hence the use of the Kullback – Leibler divergence.
III. **Internal State – Optimization.** This is the "unconscious" phase where the brain sorts the sensory signals from memory and calculates their surprise values. An optimal signal is obtained by the brain through gradient descent, which is a type of Bayesian optimization procedure, and then stored in its memory for immediate or future use.
IV. **External State –Action:** The brain interfaces with its environment but acts in accordance with the optimum signal obtained from the previous phase.

This cycle is renewed by the brain whether a final resolution is arrived at, and still continues even after a resolution has been reached, albeit on a less intense level.

Equivalence of the Free Energy Cycle and Wallas' Four-Stage Process

We now give a stage-by-stage account of Wallas' four-stage creative process using the free energy principle.

The first step in Wallas' creative process is *preparation*, and this happens when the organic brain, under the action of the conscious human being ("active state"), collects data samples (i.e., samples of sensory signals) from his environment. While the person collects data through conscious interface with his environment, the brain takes account of these data, and stores them in its memory. Thus in the process of *preparation,* there are two "learning" operations taking place at the same time in terms of collection of sensory signals, namely, one that is carried out by the *conscious* sensory perception of the person ("active states"), and the other, the transmission of these sensory signals to the brain which are then stored in its memory ("internal states"). Although the transmitting and storing of these sensory signals to the brain are reflexive, involuntary actions, overall the stage is *conscious* because of the brain is interfacing with the environment. This is the first step in the creative process of a human being considered as a functioning Helmholtz machine. The second stage in the creative process is *incubation*, and this state is mainly *unconscious,* because at this point the brain is largely left to itself to process all the data both consciously and unconsciously collected from the environment. The brain, which is now liberated from the conscious controls of the person, is free to consider myriads of combinations out of all the sensory signals gathered from the environment. The brain calculates surprise values from different samples, constrained only by the condition imposed by the FEP, which isto choose sensory signals that would steadily decrease the surprise until a minimizing one is obtained. Hence even when the person is not consciously focused at the creative task at hand, the brain still processes quietly all the data (sensory signals) that are gathered. In fact, the brain still operates as data gatherer even though the person is *not* consciously aware of it:

"…The brain as [sic] one of the best examples of an organ that is actively constructing explanations through its own sampling of the world. So, this *inactive*[italics mine] perspective is very important because not only does the brain then have to explain all the sensory input, it also has to choose which sensory input to sample. It is in charge of gathering information, evidence for its own predictions and own beliefs about the world. …" (Friston, 2016)

Hence, *incubation* is simply the stage in which the brain, purely under an internal state, calculates approximations of entropies arising from corresponding surprises in a virtual optimizing exercise. The third stage in the creative process is illumination, and occurs when the brain finally arrives at a sensory signal with minimal surprise, but only after being aided by the active state of the brain (i.e., conscious state) at the previous cycle. Consequently, the minimization of the entropy ensures at least an ideation that might prove useful to the solution of a problem.

The final step of verification, which is a conscious activity, corresponds to the point in the free energy cycle where sensory knowledge that has been processed by the brain in its prior internal state becomes the basis of the person's new active state, and repeats the optimization process through renewed interface with the environment. Thus, verification equals the fourth phase of the free energy cycle, at which point the whole creative cycle is then repeated.This creative process doesn't stop when ideation or resolution happens. The cycle operates as long as the brain interfaces with its environment. If the brain performs multiple mental tasks at the same time, then there are also multiple free energy cycles operating at the same time, and the phases where those multiple cycles are currently situated will not necessarily be the same.

Conclusion

In this paper I have shown the equivalence between the Free Energy Cycle and Wallas' four-stage creative process. The two frameworks which were established to model the creative process have stages that could be mapped into each other. In this respect, the free energy cycle is simply the mathematical counterpart of Wallas' creative process. Thus, creativity is a process that can be described as the alternationof phases of active states ("consciousness") and internal states ("unconsciousness")which the brain undergoesin its learning process as expounded in the free energy principle framework. In addition, since creativity follows the free energy principle, it follows that the brain is able to ideate, resolve, or invent when it has reached a Bayesian optimization exercise where it has found a sensory signal that minimizes surprise, and hence entropy.

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