

Criticality of the Brain and Criticality of Art

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1. Criticality of the Brain

The ability of our brain to respond to small extrinsic or intrinsic perturbations points out that the brain as a complex system is operating close to instability, or criticality, because any system at the critical state has a very high sensitivity to tiny perturbations [Haken 1996]. Per Bak gives another reason why the brain should be critical: the input signal must be able to access everything that is stored in the brain. The brain cannot be in subcritical state. In this case input signal would be access to only a limited part of information. But the brain cannot be supercritical either: in this case any input would cause an explosive process in the brain, and connect the input with everything that is stored in the brain [Bak 1996]. Hence, the waking brain must operate strongly at the critical state, where a neural network reveals Weber-Fechner logarithmic law and Steves power law [Kinouchi 2006]. The critical point maximizes information transmission within a neural network.

2. Criticality of Art.

2.1. Instability of the Compositional Balance in Painting

Pictorial balance is the most important principle of compositional design in painting, sculpture, and architecture. R.Arnhelm defined pictorial balance as the appropriate distribution of optical weight in a picture [Arnhelm 1964]. Optical weight refers to the perception that some objects appear heavier than others. Dark colors, unusual shapes, larger objects, and unstable elements look heavier than light colors, regular shapes, small objects, and stable elements of a picture. Compositional balance is achieved when

pictorial elements are grouped in such a way that their perceptual forces compensate one another.

Example of compositional balance between unstable state of the small girl staying on the ball and stable state of the athlete sitting on the cube on Pablo Picasso's painting "*The Young Girl on the Ball*" is shown on Figure 1.



Figure 1. Compositional balance P.Picasso's painting "*The Young Girl on the Ball*". Pushkin's Museum of Fine Art, Moscow, Russia

Compositional balance principle is a holistic principle resulting from the joint effects of the physical components of a stimulus field and therefore can not be afforded by any one element alone.

D.Chek Ling Ngo and L.Seng Teo proposed an objective measure for quantitative evaluation screen layouts balance for computer graphic but this method does not fit for investigation of painting pictorial balance [Chek Ling Ngo D 2001].

More promising for painting is empirical approach based on eyes-movements studies. As one gathered information from a picture, the eyes move in rapid jumps or saccades followed by pauses of fixation. The average duration of fixation is typically between 200 and 300 milliseconds. The map of the location of fixations, called a scanpath, provides a graphic record of how information is selected and processed perceptually as a viewer looks at a picture.

One of the first eye-movement investigations of pictorial balance in painting was the work by Nodine in 1982 [Nodine 1982]. Nodine created a less-balanced version of each examined painting by cutting a copy of original apart and rearranging the pictorial

elements. Comparison of fixation times of original versus altered version of paintings revealed that a change in the balance structure of the compositions produces a change in the pictorial weights (by changes in viewing time) of the key elements of the paintings.

As well known, balancing state may be stable or unstable. No doubt, R. Arnheim considered compositional balance in painting as a stable state. Indeed, he wrote in his book "Art and Visual Perception": "It must be remembered that visually, just as physically, balance is the state of distribution in which everything has come into standstill.....In physics the principle of entropy, also known as the second law of thermodynamics, asserts that in any isolated system each state represents an irreversible decrease of active energy. The Universe tends toward a state of equilibrium, in which existing asymmetries of distribution will be eliminated" [Arnheim1964].

Of course, compositional balance in painting is always unstable, because adding or removal of any element in a canvas upsets this balance

3.2. Instability in Literature

Ability to excise control over unstable states is a basis of many circus arts (for instance, rope walking) and, of course, of ballet art. In other types of choreographic art - folk, ball and modern dances the unstable elements are also widely introduced, though very frequently they do not have such a perfectly expressive nature as in ballet. A great deal of elements of figure skating, gymnastics, acrobatics also saturated by unstable in their nature states.

Before we proceed to the discussion of instability in literature it is necessary to dwell on the meaning of this conception as regards the literary genre because generally it does not coincide with the mechanical meaning of instability that we deal with in the art circus and choreography.

The most adequate mathematical apparatus for the description of situation in belles-lettres may be the theory of games which is nowadays widely used in various models of behavior basically in conditions of conflict. In these models the parties making decision are called "players" and the action they choose are called "strategies". When two players take part in a game, any pair of strategies is called "situation".

In the theory of games the definition of instability named "the Nash", after American mathematician John Nash. According to the Nash, some situation becomes apparently unstable, because it is about to break down, either because factors leading to that possibility exist or because one of the players obtains the best result by means of a unilateral choice of his strategy.

For example, a hare and a wolf living together is an unstable situation. Moreover, the essence of instability in the theory of games and in the mechanical models, for instance, of balletic art is the same: Unstable states are momentary by their very nature and rapidly break down. But the causes of their short duration are, certainly, different.

Now let's look at instability in literature. Let us start with fiction, the literature of an entertaining genre. When in a detective story a crime is committed, the criminal according to the Nash appears to be in unstable position: because at this moment his life at large is incompatible with penal laws. The duration of the instability depends on adroitness and skill of both the criminal and organs of justice.

In general, instability in literature of an entertaining genre can be described as follows: Some value (life, honor, wealth, or power, for example) is in danger, but

owing to personal traits of the heroes of the books and sometimes to favorable coincident this value is preserved.

This does not mean that instability can be met only in fiction; it is widely presented in classical literature as well. In Shakespeare's "Hamlet" the main character learns the name of his father's killer at the beginning of the first act, but he takes vengeance only at the end of the tragedy, thus, unstable state, King Claudius' life is preserved throughout the play.

In "Hamlet" there are instabilities in interpersonal relations that can be precisely defined with the help of the notion frustration from the theory of spin glasses [Toulouse 1979]. Let us consider the central characters of the play: King Claudius, Queen Gertrude, and Prince Hamlet.

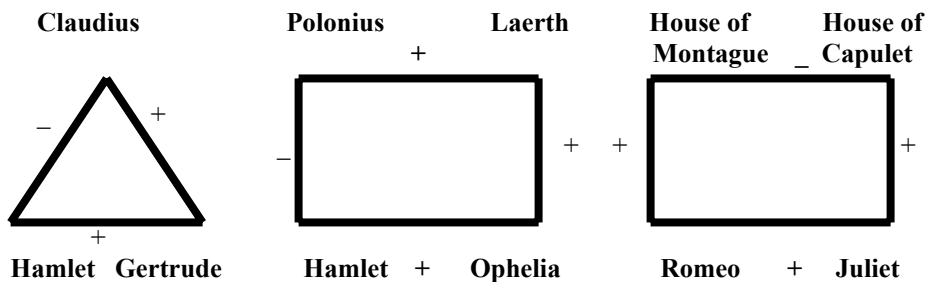


Figure 2. Frustrating bonds in plays by W. Shakespeare.

The triangle formed by the interrelations between these personages is obviously a frustration configuration (Figure 2a) and therefore this structure is metastable. Another frustrating contour is Hamlet's relations with Polonius's family (Figure 2b) at the beginning of the play. Shakespeare often brought such types of instabilities into his plays. Figure 2c is a graph of interrelations in "Romeo and Juliet" which is also frustrating configuration.

If we carefully analyze all the examples of unstable states in fine art considered above we may conclude that these instabilities perform the functions of the order parameter and subordinate the whole composition of the artwork.

The order parameter can be compared with a well-known conception of "dominant" "in the studies of art. The most typical definition of the concept of dominant is [Vygotsky, 1971]:

"Any story, poem, or picture is a complex unity made up of absolutely different elements that are differently organized and are in different hierarchic subordination and connection; in that complex unity exists a prevailing moment which determines the structure of the whole story, the meaning and the purpose of each part of the story".

L.S. Vygotsky has brilliantly demonstrated the validity of the synergetical slaving principle through the example of I.A. Bunin's story "Light Breathing". Chronological progression of the events depicts a distressing, tragic story of a provincial life. Actually, the writer arranges all the events in such a way that the burdens of life are gone. All non-chronological skillful leaps from one event to another used to develop the plot are aimed at softening and eliminating the spontaneous impression of the events taking place and forming quite opposite impression.

While reading the story "Light Breathing" L.Vygotsky and his co-workers registered breathing. It turned out that even when reading about the murder and death of a hero the reader breathed lightly and freely, as if he did not perceive the horrible events but some liberation from the horror.

No doubt, this psychological state of lightness and freedom is unstable in this story.

3. Long Range Correlations in Artworks

Recent investigations show that the most interesting peculiarity of our visual world is the scale invariance of natural images. Mandelbrot have shown In the 1970th that many of natural patterns: landscapes, mountains, coastlines, clouds, trees and so on are fractal [Mandelbrot 1982].

Natural landscapes are prime examples of complex systems with fractal properties. What are the general principles governing the formation of landscapes? Mathematical models in geomorphology using the theory of self-organized criticality explain fractal features of natural landscapes. According to Per Bak all the variability of Earth landscapes (including mountscapes) can be regarded as an self-organized critical phenomenon [Bak 1996]. .

R.Voss and J.Wyatt estimated fractal dimensions of early Chinese landscape painting analyzed of digital image intensities $J(x,y)$ [Voss 1993]. Space representation changed drastically during Sung dynasty (960-1279 A.D.), when landscape painting reached the highest development in China. It turned out that landscapes painted at the beginning of this period have fractal dimension in the range 1.3-1.4, while the later paintings have fractal dimension in the range 1.07-1.13.

The paintings of US artist Jackson Pollock possess fractal properties. Richard Taylor and his colleagues analyzed Pollock painting produced between 1943 to 1952 and shown that fractal dimension of his works increased from 1.1 to 1.7 [Taylor 2003].

There are some preliminary data indicating that color palette in painting one can trace some characteristics that are subordinated to power law of distribution. In a painting were investigated some portions of areas painted in one color. From the reproduction of canvases were cut out the places visually perceived as one-colored and these places were sorted by color. Then each group of one color was weighted upon analytical scales. So far as the paper upon which were printed the reproductions was uniform in thickness, the weight of each heap appeared to be proportionate to a total area of the entire number of pieces in one heap.

It turned out, that in the most different pictures the colors occupying approximately 95 per cent of pictures area and about two-thirds of its color range can be satisfactory described by power law formula [Orlov 1980].

The Harvard linguistics George Kingsley Zipf was the first, who revealed power law in rank distributions of words in English language texts, including literature works.

$$P = \frac{a}{r}$$

where a - constant and r – rank.

A.Schnkel, J.Zhang, and Y.Zhang explored long-range correlations in various human writings [Schenkel 1993]. The Bible turned out the closest to ideal power law.

4. The Wundt Curve

Arousal response curve well known as the Wundt curve looks like an inverted 'U' shaped curve, is sketched in Figure 5. Berlyne refers to the Wundt curve as a hedonic function" [Berlyne, 1971].

The relationship between "arousal potential" of artworks and "hedonic value" can be explained from the theory of criticality standpoint, more exactly, the theory of second order phase transition. Order parameter equation for the second order phase transition can be written as a "cusp" catastrophe $\Phi^3 - (K_c - K)\Phi - C = 0$

The "arousal potential" (novelty, unexpetedness and so on) Φ in this model is the order parameter. Sophisticated measures of novelty have been developed by several researchers (see, for instance,[Kohonen 1993].

hedonic

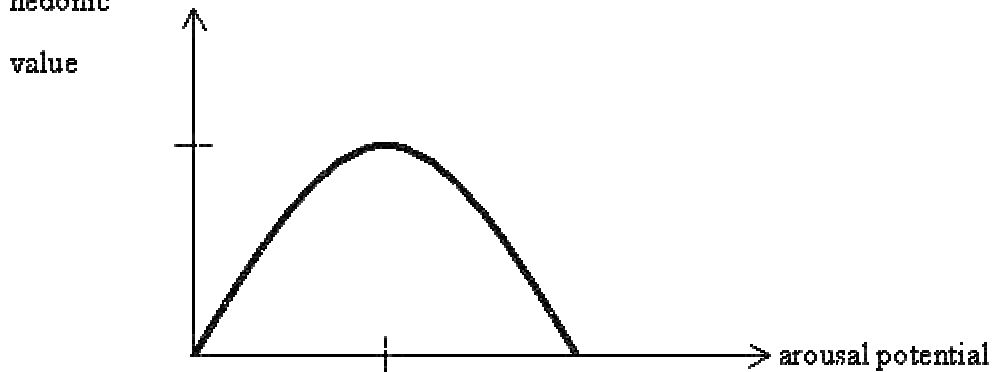


Figure 3. The Wundt curve.

"Hedonic value" K plays the role of control parameter (like temperature in Ginzburg-Landau model of phase transition).

1.5. Mutual Information between the Brain and Art

Mutual information $I(A,B)$ between the artwork and the brain could be written using well-known Shannon expression:

$$I(A,B) = H(A) + H(B) - H(A,B)$$

$H(B)$ - entropy of the brain is very high at critical state

$H(A)$ -entropy of the artwork is very high if artwork is at critical state

$H(A,B)$ -mutual entropy of the brain and the artwork is very small when both are at critical state because mutual correlations between the brain and the artworks are very high.

Therefore mutual information $I(A,B)$ reaches the maximum magnitude when both the artwork and the brain are at critical state.

6. Conclusion

All natural complex system, such as biological, ecological, economical exist at the edge of chaos and order. In the theory of complexity has been able to show that human brain and behaviour also are at critical point. Now we can declare that any masterpiece and outstanding artwork exists near critical point and art as a whole exhibits all properties of self-organization: non-equilibrium phase transitions [Yevin 2001], multistability under perception of ambiguity [Yevin 2000], etc. Perceiving critical phenomena in artworks human brain have to operate near criticality. Therefore, the art should be regarded as a tool for supporting human brain at critical state.

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