Estimation of the Capacity of Human Perception using Computational Aesthetics

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Abstract— **The paper is part of a broader study to utilize some hypotheses, methodologies and tools from Computational Aesthetics, the foundations of which were created in C.R. Shannon's "The Mathematical Theory of Information". Using the basic ideas of computational aesthetics, a picture can be seen as a message. Cybernetic aesthetics introduces information flow to describe perceptible information. Further cybernetic aesthetic proposes characteristics for conspicuity and intelligibility of artwork. In the sample survey, using these variables, we try to measure the quantity of perceptible information in the image. In the literature, human perceptual capacity values are reported close to 15 bits per second. Our aim will be to verify this information. We will do our study with 200 responses of 35 respondents, where we will measure their ability to perceive different elements in M.C. Escher's "wallpaper" paintings. Part of the study will be a statistical evaluation of the measurement.**

Keywords—aesthetic characteristics, cognitive information flow, human perception

I. INTRODUCTION

Gradual development of the scientific concept of aesthetics has had several phases. Rational aesthetics perceives aesthetics as subjective knowledge, perception, or feeling. Since the late 1930s, art has been perceived as a message whose aesthetics can be evaluated and described using mathematical and statistical approaches. Informational aesthetics comes with an idea, that the aesthetic value of an aesthetic object can be scientifically measured. David G. Birkhoff considers aesthetic information as result of the interaction between Order and Complexity, see [1] and [14]. Birkhoff's measures have been explored as psychological experiments, see [17]. Alfred North Whitehead introduces negentropy (inverted physical entropy) as a process. John H. Shannon considers aesthetic information as part of (human) communication. Cybernetic aesthetics delineates information flow to explain perceptible information. Norbert Wiener (1894-1964) formulates Wiener cybernetics (feedback systems), which allows us to grasp the communication channel, [16]. Generative aesthetics uses a computer for artistic creation with help of rules for creating aesthetic information. Cf. [15]. In the mid-1950s, Max Bense and Abraham Moles formulated an information aesthetic that seeks to propose theories for describing the amount and quality of information in aesthetic object. Cf. [2], [3], [7], [9], [10] and [11].

All approaches have reached their limits. When assessing an aesthetic work, subjective perception and aesthetic experience cannot be completely neglected. It is not possible to find and describe the degree of aesthetics, independently of the sentient person and the context (it always depends on the mood of the viewer). If we want to perceive aesthetics as a communication process, it is necessary to first describe and harmonize the relationship between communication and art. There is a need for a wider view of the different expressions (various statements) of what aesthetics really is.

Human perception could not, almost certainly, exist without information, nor without flow of information. Different people may generate different information from the same data given their differing education, age, mental state, beliefs, and expectations. Of course, not everyone marches to the same step.

Opportunities for the viewer to reveal all hidden information in the picture is related to the degree of complexity of the image. Computational aesthetics suggests formulas for calculation of painting's information content, its intelligibility and conspicuity. The efficiency of the transmission of all parts of the message (image) can be mapped using an information flow that indicates the number of transmitted information per unit of time. A core idea of information flow is based on Shannon's article [12] and book [13].

Our goal will be to find out for what values of the information flow is processing realistic, and for what values of the information flow is impossible. The boundaries of human perception will be examined in a sample survey, based on the observation of several images formed by groups of different elements. Cf. [4]. The main objective will be to estimate the maximum achievable cognitive flow of information. In the third chapter, we describe the experiment where we select 6 paintings of M.C. Escher. Through participants in the sample survey, we will monitor how the observed number of different elements is affected by the time of viewing the image. Each participant will gradually see (in different order) a group of six M.C. Escher paintings. The participant will then be asked to find all the elements whose number will be revealed to him. The obtained measurements will be statistically evaluated in the study.

A. Cybernetic aesthetics (60s and 70s of the 20th century)

The creators of cybernetic aesthetics have been linked to information aesthetics. Herbert W. Franke (born 1927), Siegfried Maser (1938-2016) and Helmar G. Frank (1933-2013) have continued in information aesthetics, focusing on the psychological aspects of information aesthetics. Maser focused on numerical aesthetics, see [8].

Frank and Franke tried to unify the approaches used by Bense and Moles. See [5], [6]. They both perceived Mole's work, which described the relationship between perception and information theory, as relevant to information psychology. Mole's view was taken as the basis of Frank and Franke's aesthetic principles.

In literature we can find five criteria for aesthetics: Syntactic density, Semantic density, Syntactic repleteness, Exemplification, Multiple and complex reference.

According to Moles, there can be no passive aesthetic perception, because the artwork is always the object of communication.

Franke explored the capacity of an information flow that is able to be assimilated with one's senses. He recorded a paradox in artistic information. When watching works of art that are expected to have a long-term effect, and therefore a high degree of complexity, the physical capacity of the people is somewhat limited. Excessive artistic information leads to irritation of the person, while a lack of artistic information slides into boredom. Franke proposed a multi-plain model to achieve a degree of complexity without exceeding the absorber capacity. He introduces concepts as an information system and active audience engagement. On a long-term basis, this concept has not led to confirming certain weaknesses in information aesthetics. This conception leads, however, to an idea that aesthetics and artistic values can be expressed as quantified and rational criteria. Frank and Franke have reached their own methodological boundaries. They have come to the conclusion that artistic values cannot be expressed solely on the basis of the visual appearance of the image, but it is at least partially a subjective feature depending on the viewer.

B. *Reception aesthetic*

American psychologist Fred Attneave (1919-1991) introduces the concept of "conspicuousness," and Austrian artists Herbert W. Franke works with the term "degree of communicativeness of a work".

Helmar G. Frank focused on the processes of perception of art and designed a multi-plain model. He proposed extension of the communication process. He also talked about the fact that aesthetic information is not only dependent on one-way communication, but must also allow the object (object) to go beyond the listener (viewer) and behave, in the context of art, as a transmitter.

II. Information Flow and Mathematical Formulas for the Calculation of Image Imaginativeness

Using Shannon's approach, we can see the painting as a message. The amount of information hidden in the picture is determined by the probability p_i of the occurrence of individual characters representing part of the image. Ideas for message analysis (which can also be images) is the division of the image into elements and the determination of the degree of complexity of the image, i.e., its organization and its degree of indeterminacy. Cf. [1], [4], [13]. The quantity of information is greater if the character is less expected. The measure of information is defined by the so-called entropy, which has a 1 bit unit:

$$H_i = log_2 \frac{1}{p_i} = -log_2 p_i \, , i = 1, \dots, n. \quad (1)$$

For the whole picture this relationship is:

$$H = \sum_{i=1}^{n} log_2 \frac{1}{p_i} = -\sum_{i=1}^{n} log_2 p_i \; . \quad (2)$$

Maximum entropy reaches the image at the same probability, i.e. with uniform distribution of elements.

Computational aesthetics define the information content of an image (formed by N elements) such as:

$$I = N \times H = N \times -\sum_{i=1}^{n} log_2 p_i \; . \quad (3)$$

If the image is made up of N elements made from n type of characters, we get:

$$I = N \times log_2 N. \quad (4)$$

Redundancy is given by:

$$R = \frac{(H_{max} - H)}{H_{max}} = 1 - \frac{H}{H_{max}}. \quad (5)$$

Relative redundancy is:

$$h = \frac{H}{H_{max}} = 1 - R \; . \quad (6)$$

Redundancy increases the overflow of some parts of the message and reduces the efficiency of the information transfer. At the same time, however, it increases the chances of a correct understanding of the message after its transmission and thus contributes to the intelligibility of the message.

The flow of information (Informationsfluss) is defined as:

$$I_f = \frac{I}{t} \quad (7)$$

and indicates the number of transmitted bits per unit of time.

Transmission is via a channel that has a limited capacity C_k. The channel is able to release the flow value

$$C_k = sup(I_f) \; . \quad (8)$$

It is said that perception is determined by a memory that allows the memory of characters to move between 5s and 12s. Computational aesthetics then considers time T = 8s. The capacity of human perception is considered to be between 12 and 25 bits per second. Computational aesthetics then considers capacity C = 16 bit/s.

The parameter describing the perception of information is

$$K_k = C_k \times T = 128 \, bit. \quad (9)$$

This value is the upper limit to the comprehensibility of the art work.

Value of surprise (Überraschung) is:

$$U = \frac{\log_2 \frac{1}{p_i}}{H} = \frac{-\log_2 p_i}{-\sum p_i \log_2 p_i}. \quad (10)$$

For U=1, computational aesthetics consider the character to be neutral, U<1 for banal, U>1 as surprising.

Conspicuousness (Auffälligkeit) is defined as:

$$A = p_i \times U_i. \quad (11)$$

It is reported that psychological research has shown that maximum conspicuity is achieved for value A in the range of 0.33 to 0.47.

III. Expample of Calculation

In the painting "Fish vignette" by M.C. Escher we mark black fish, white fish and red fish as elements of z_1, z_2 and z_3.

Fig. 1. Fish vignette by M.C. Escher

Probabilities p_i of the occurrence of individual elements are:

$$p_1 = \frac{7}{13},\ p_2 = \frac{5}{13},\ p_3 = \frac{1}{13}.$$

According to the formulas (1)-(11) above, we get:

$$I = 13\ log_2\, 13 - 7\ log_2\, 7 - 5\ log_2\, 5 - log_2\, 1 = 16.84\ bit\ .$$

$$H = \frac{I}{N} = \frac{16.84}{13} = 1.30\ bit.$$

$$H_{max} = log_2\, 13 = 3.70\ bit.$$

$$R = 1 - \frac{1.30}{3.70} = 64.98\ \%.$$

$$I_f = \frac{I}{T} = \frac{16.84}{8} = 2.11\ bit \cdot s^{-1}.$$

Value of surprise is:

$$U(z_1) = \frac{-log_2\frac{7}{13}}{1.30} = 0.68.$$

$$U(z_2) = \frac{-log_2\frac{5}{13}}{1.30} = 1.06.$$

$$U(z_3) = \frac{-log_2\frac{1}{13}}{1.30} = 2.84.$$

IV. Experiment

A. *Choice of test images*

We used 6 paintings, with the number of different elements *n* increasing from 3 to 8. All 6 images were displayed in a random order to the respondent. Subjects were always informed about the true number of different elements. Then they looked at the painting until they found all the different elements. After finding all element classes, the respondents clicked the button „Done“. The webpage measured the duration of the experiment, until respondents found all of the different elements in the image. The session typically lasted between 3 and 10 seconds.

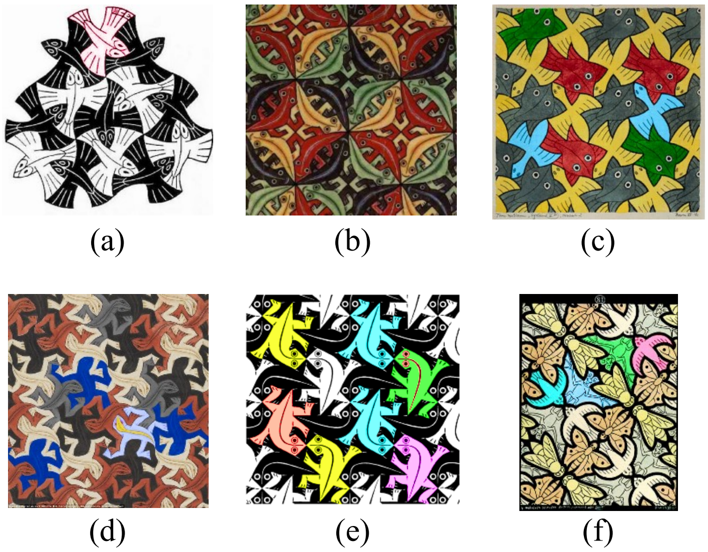

Fig. 2. Sample of six M.C.Escher paintings.

B. *Characteristics of painting*

According to the formulas (1)-(11) above, we calculated characteristics of chosen six paintings. The results are shown in the table I.

C. *Response time measurement and results*

For each image, we first determined the average response time required to find all the elements t_{avg}. The characteristics of the images are given in Tab. I. The table II summarizes the mean and standard deviation of participant's viewing time distribution. IF is the measured information flow and it's computed as:

$$IF = \frac{I}{t_{avg}}. \qquad (12)$$

In Tab. II we see how the average times increase depending on the complexity of the images. Using ordinary least squares we can explore how painting characteristics influence time of responses. Tab. III presents the estimated parameters of the regression line and the indexes of determination for the various explanatory variables. The largest determination index values (all greater than 0.8) were for n, R, H. The explanatory variables I and I_f had determination indices around 0.6. Only the N and H_{max} variables had a determination index of approximately 0.4.

TABLE I. NUMBERS OF TYPES OF ELEMENTS, NUMBER OF ELEMENTS AND CALCULATED PAINTING CHARACTERISTICS.

	(a)	(b)	(c)	(d)	(e)	(f)
n	3	4	5	6	7	8
N	13	24	20	23	16	24
I	17	48	42	55	36	63
H	1.3	2	2.1	2.39	2.25	2.625
H_{max}	3.7	4.58	4.32	4.52	4	4.58
R	65	56	51	47	44	43
I_f	2.11	6	5.25	6.875	4.5	7.875

Source: own.

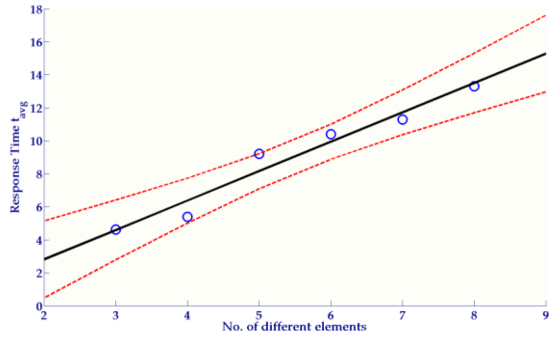

Fig. 3. Dependence of the number of different elements in the image on time of response.

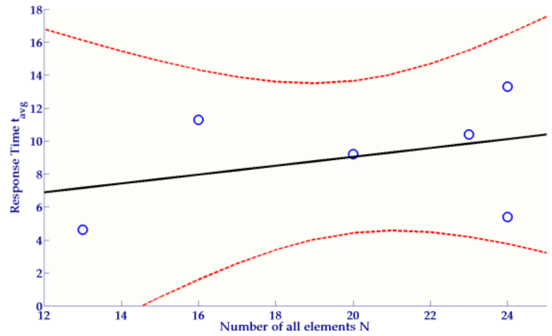

Fig. 4. Dependence of the number of all elements in the image on time of response.

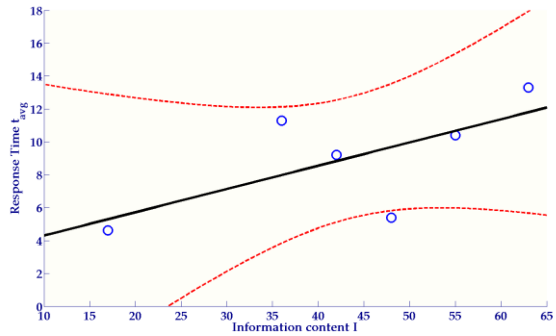

Fig. 5. Dependence of the characteristic I (information content) on time of response.

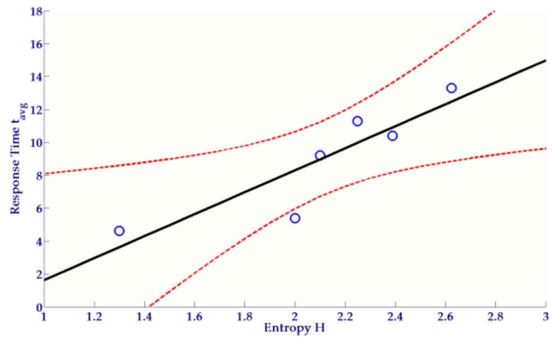

Fig. 6. Dependence of the characteristic H (entropy) on time of response.

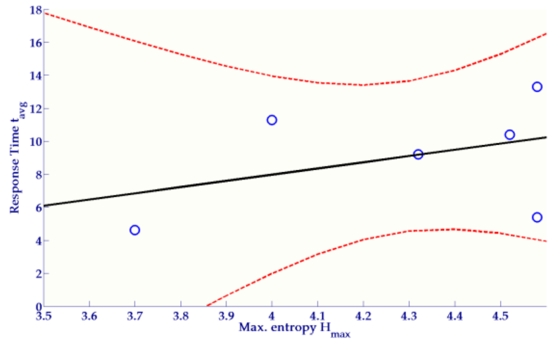

Fig. 7. Dependence of the characteristic H_{max} (maximum entropy) on time of response.

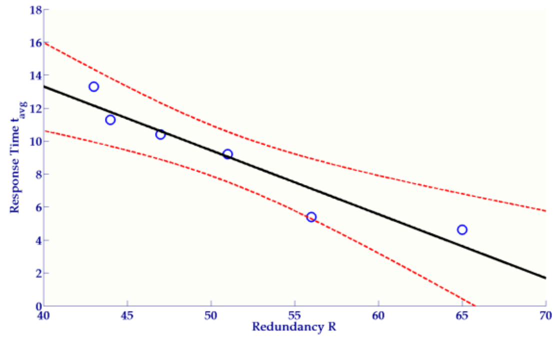

Fig. 8. Dependence of the characteristic R (redundancy) on time of response.

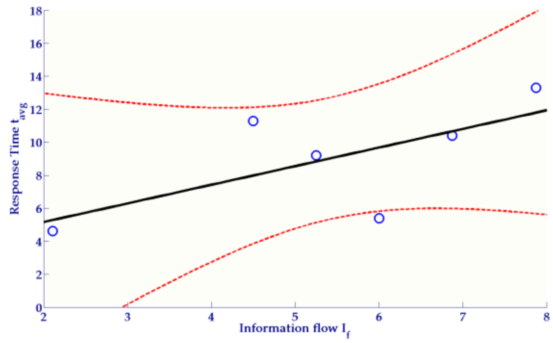

Fig. 9. Dependence of the characteristic I_f (flow of information) on time of response.

TABLE II. THE OBSERVED TIMES

	(a)	(b)	(c)	(d)	(e)	(f)
t_{avg}	4.61	5.41	9.20	10.41	11.30	13.32
Std. dev.	6.61	4.14	12.37	5.24	7.96	7.58
IF_i	3.69	8.88	4.56	5.28	3.18	4.73

Source: own.

TABLE III.

	n	N	I	H	H_{max}	R	I_f
I^2	0.9785	0.3647	0.6671	0.8895	0.3994	0.9514	0.6674
$\widehat{\beta_0}$	-0.7673	3.6414	2.8904	-5.0540	-7.0902	28.8196	2.9056
$\widehat{\beta_1}$	1.7837	0.2701	0.1414	6.6784	3.7665	-0.3878	1.1292

Source: own.

In figures 3-9 we can see the dependence of the characteristics on the response time. Regression lines as well as (1-α)-confidence domain with α = 5% were constructed. The narrowest confidence domain is for the dependence between the number of elements and the response time, and for dependence between redundancy and the response time. See Fig. 3 and Fig. 8. The most important result is Fig. 9, which shows an increase in response time when the flow of information is increased.

Further, we determined basic descriptive statistics (averages and standard deviation of IF) for all responses, see Tab II. Then we can construct a confidence interval for the mean value of the information flow as follows:

$$\overline{IF} \pm t^{*}_{205.1-\frac{\alpha}{2}} \frac{s_{IF}}{\sqrt{205}} = 7.8918 \pm 1.976 \frac{7.6236}{\sqrt{205}} = (6.8397, 8.9439)\ bit \cdot s^{-1}. \qquad (13)$$

The values of perceptual limits presented in the literature are larger than our estimate. But this may be due to the different design of the experiments and the complexity of Escher's images.

V. CONCLUSION

Computational aesthetics suggests various characteristics measuring the complexity of images that are made up of different elements. These characteristics are: conspicuity, surprise, information content.

The primary objective of this study was to examine participants' viewing time distribution until all element types are seen. We used six images of M. C. Escher for testing. Respondents were acquainted with the number of different elements that appeared in the image. In the sample survey, we measured the time for respondents to find all element types. In the statistical analysis, we tried to find out in what values of the information flow, the respondents were able to recognize all the elements.

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