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Computer-Aided Aesthetic Evaluation of Visual Patterns

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Abstract

Exact aesthetics is a discipline that connects the realm of visual arts with the science by integrating computers into processes of design and its objective criticism. The paper provides a short overview of exact aesthetic measures describing information and structural qualities of simple visual stimuli endowed with some regular structure. An algorithmic system performing aesthetic evaluation of such computer-generated patterns is introduced thereafter.

1. Patterns and Perception

Modern communication relies heavily on visual information processing. The language assembled from text, images, signs and icons is largely descriptive and informative, yet it must not be always true that 'a picture is worth a hundred of words'. We frequently experience difficulties when orienting in multidimensional communication environments. It can be observed from reading newspapers, watching TV commercials, using visual communication interfaces, or just from autonomic absorbing of scenes such as in Figure 1, that certain graphical depictions are easily approachable whilst others require an increased effort to be ingested — or, their message may elude a perceiver entirely.

It is firstly a proper form of visual stimuli that determines their fluent reception. A low-level form — a primordial information about a stimulus being sensed — can be identified with a *pattern*, an observable and distinguishable property of images, emerging from a configuration of their constituting elements. Generally stating, 'rhythmical' structures manifesting a refined arrangement of visual elements have proven to be comprehensible better than structures that demonstrate only a few accredited design standards [2, 5].

In this paper, patterns are examined with algorithmic tools in order to achieve a numerical assessment of their 'exact aesthetic potential'. When appropriate measures are discovered and verified in computer-adided aesthetic systems, the task of distinguishing between good and poor design may be once accomplished by automated means.

2. Information Measures

Images of an apparent structure can be treated as messages conveying some mensurable amount of aesthetic information. If structural elements — *symbols* forming a pattern — are examined for occurrence and distribution characteristics, the overall visual appeal is determinable from a balance among their coherence and exceptionality. When a pattern consists of elements the occurrence of which cannot be predicted in a computable way, the message will be declared as incomprehensible. The maximal aesthetic experience comes about when the symbols appear in recurring, yet varying clusters. Let's now engage more intimately in individual information aesthetics measures.

Figure 1: Letters, signs and images forming visual patterns. (Photo : courtesy of Japan-Guide.com.)

Entropy H is a descriptor of indeterminacy, specifying the amount of information that must be absorbed to sense the structure of a pattern. The entropy reflects a fact that the least expectable symbol induces the biggest increment of information. Isolated instances of unique symbols distributed over the message, not accompanied with redundant data, are those to be appraised as 'eye-striking'. The highest information increment is expected to arrive with symbols that have never been perceived yet, or that otherwise prove the lowest occurrence predictability at a given position. The information potential of a pattern — measured in bits — decreases with recurring instances of m different symbols s_i, appearing in the message with probabilities P_i :

$$H = -\sum_{i-1}^{m} P_i \log_2 P_i \,.$$

A measure of *information content I* combines the entropy H with the scale N of a pattern. The amount of information increases with the length of a message, as well as with its symbols' unexpectedness. A preferable design manifests both the content diversity and form compactness ; such arrangements tend to be appraised as engrossing. Less interesting patterns have to compensate weaker aesthetic dispositions with an extensive size :

$$I = N\,H \,.$$

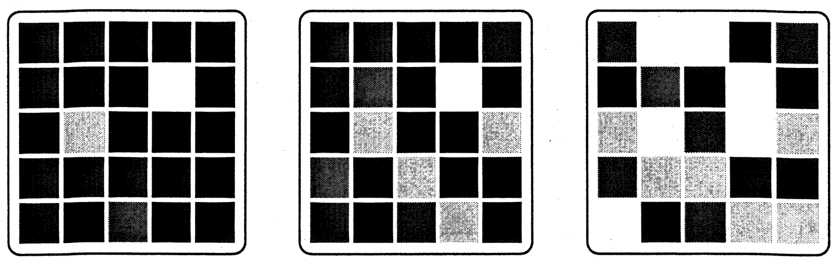
Information flow I' is a measure assessing principal transmission qualities in time t. Messages delivering only a small piece of information within a given time interval will be likely considered as unattractive ; on the contrary, it is difficult to comprehend visual stimuli that carry too much information, even after a longer time :

$$I' = I/t \,.$$

We are physiologically restricted to memorize approximately each twentieth bit of information in the volume of data we perceive [1]. This is one of the reasons why it is difficult to understand messages with higher entropy — too much information kept temporarily in the memory delays establishing structural relations among perceived symbols of a complicated pattern. Therefore it is desirable to incorporate certain symbols into the pattern that make unforced yet distinct references to the information revealed before. These symbols can be called redundant in a sense that they do not increase the information content as much as they improve the information transmission. The *redundancy* R specifies how much dispensable is the information conveyed with a message the entropy of which doesn't reach the maximal value $H_{\max}$:

$$R = 1 - H/H_{\max}.$$

Redundant symbols appearing at appropriate positions are required for better comfort and contentment to be experienced by recipients of the message. A simple evaluation of patterns using the introduced information measures is illustrated in Figure 2.



$H_\blacksquare = 0.2\,\mathrm{b}$, $H_\boxtimes = 4.6\,\mathrm{b}$	$H_\blacksquare = 0.6\,\mathrm{b}$, $H_\boxtimes = 2.6\,\mathrm{b}$	$H_\blacksquare = 1.8\,\mathrm{b}$, $H_\boxtimes = 2.1\,\mathrm{b}$
$H_\boxdot = 4.6\,\mathrm{b}$, $H_\square = 4.6\,\mathrm{b}$	$H_\boxdot = 2.6\,\mathrm{b}$, $H_\square = 4.6\,\mathrm{b}$	$H_\boxdot = 2.1\,\mathrm{b}$, $H_\square = 2.1\,\mathrm{b}$
$I = 18.0\,\mathrm{b}$, $R = 64\,\%$	$I = 36.1\,\mathrm{b}$, $R = 28\,\%$	$I = 50.0\,\mathrm{b}$, $R = 0\,\%$

Figure 2: Different patterns made of four symbols : the left-most image is redundant, the right-most one is random, the middle pattern is an aesthetic compromise.

There are lots of additional metrics that can be derived from the entropy and redundancy to describe specific pattern qualities. For example, a relative entropy may be acknowledged as a measure of local *amazement*, denoting a relative portion of information encompassed in every symbol of the evaluated image. Similarly, the measure of *exceptionality* binds the temporal symbols' incidence with their stylistic function to distinguish whether a certain motif is visually prominent or if it disappears in a background. Corresponding mathematical representations are logical and rather simple, yet such effort runs beyond the scope of the paper ; exact definitions can be found for instance in [7].

3. Structure Measures

A repertory of information measures introduced in the preceding paragraphs can be further enhanced with functions assessing the visual structure of images. Disclosing and observing patterns are a great source of aesthetic experience and attraction. Patterns recognized in an arrangement of symbols result in evocations of order, or a 'vitality' associated with the scene being sensed [3].

Order O is an attribute of well-established images, emerging from a predictable and harmonious configuration of symbols. A trivial measure of order can be proposed as the number of axial and rotational symmetries observable in the image. Further, measures of proportion, balance, unity, or cohesion can be incorporated into the order definition [6]. However, an apparent disadvantage of such concept is that over-accurately arranged patterns may be sometimes discarded as monotonous and hence boring. Minimalist images displaying a single object alone, or structures based on a simple construction rule that duplicates a certain motif regularly over the image, will be perceived as highly ordered yet aesthetically sterile.

Such arrangements prove the simplest structural level of order — an unexciting homogeneity, which is a manifestation of mere orderliness. An improvement of the order assessment with a notion of complexity is therefore needed to turn the orderliness into a true measure of thrilling design.

Let *temperature* T play the role of a plain (or disorganized) complexity. The function takes notice of different symbols and visual structures appearing in a pattern, thereby denoting its richness. The temperature drops with a meager selection of symbols, converging to zero for uniform images.

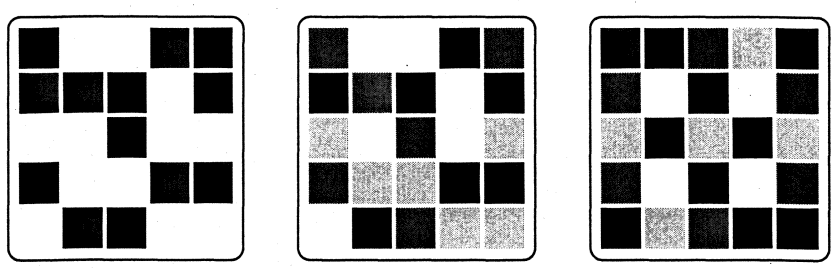
Unlike the temperature that is dependent only on the number of distinguishable symbols forming a pattern, the *organized complexity* C notices the level of their internal structure relative to the maximal order O_{max} as well. This prevents nontrivial images, proving an extensive degree of the order at the same time, to be rejected from aesthetic considerations. The complexity of patterns with equal temperatures decreases with a systematic arrangement of their symbols, and raises with the order deficiency :

$$C = T\ (O_{\text{max}} - O)\ .$$

Finally, the measure of *life* L combines the order with the temperature so that it can recognize in all respects harmonious and rhythmical design :

$$L = T\, O\, .$$

Patterns demonstrating high life are typically appraised as appealing ; their aesthetic interpretation is straight despite local structure irregularities. Contrary to organized images that are regarded as lifeful, low-life patterns are mostly perceived as complicated or even random. An elementary example of the structural evaluation is presented in Figure 3.



$O = 1.00,\ T = 1.00$ $C = 8.00,\ L = 1.00$ | $O = 0.13,\ T = 2.50$ $C = 22.19,\ L = 0.31$ | $O = 1.80,\ T = 2.75$ $C = 24.75,\ L = 4.95$

Figure 3: Different structural configuration of patterns : left-side images are lifeless, images on the right are complex ; the right-most pattern combines complexity with a satisfactory level of life.

4. Aesthetic System Implementation

Arthur is a rule-based aesthetic system supporting algorithmic design and evaluation of combinatorial images, textures and patterns, a subset of which can be appraised as an 'algorithmic art' [4] (see the homepage for details and downloads at http://fosforos.fi.muni.cz/~arthur/). The system is inspired by cybernetic models of aesthetic reasoning proposed in [8] ; its interface is depicted in Figure 4. *Arthur* employs stochastic context-free rewriting grammars together with appropriate construction rules to create patterns based on a regular division of the plane. Besides the design rules, it is a selection of symbols — color pixels or textured tiles — that particularizes the resulting image.

The aesthetic system is remarkably open to users' creative aptitude ; the user — an artist or a designer — can import ready-made tiles or let the program create its own symbolism. Symbols are placed

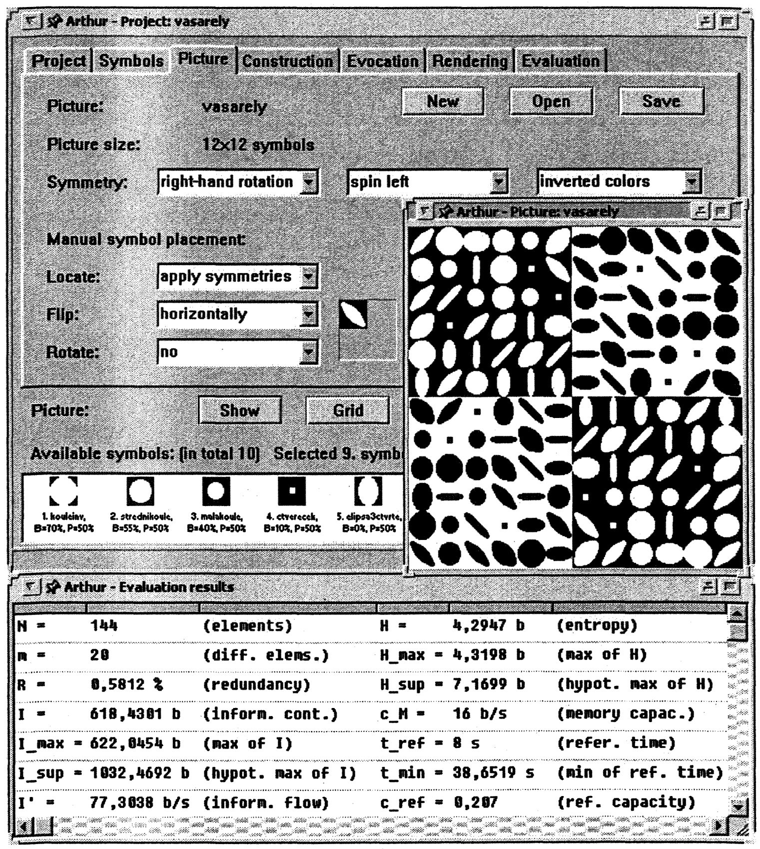
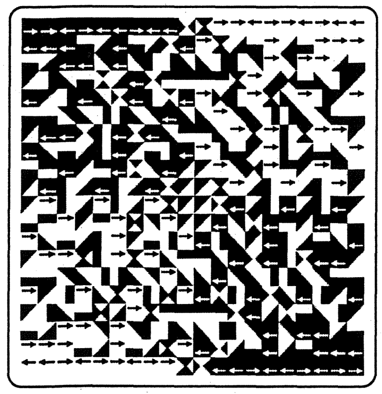


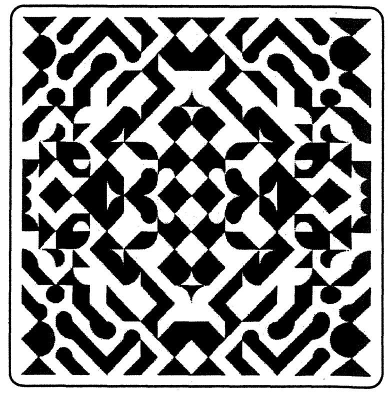
Figure 4: *Arthur*'s interface consisting of the control, rendering and evaluation windows.

over the image algorithmically by performing commands of an implemented visual grammar; patterns can be also 'sketched' manually in a built-in editor and made up afterwards by an algorithm. A nature of applied rules manifests in various rendering styles of patterns, ranging from rigorously deterministic to unpredictably stochastic images. In the latter case, the program controls a course of the image generation by a wide range of evocation criteria concerning visual properties and appearance preferences of individual symbols. Due to its generative capabilities, the system supports virtually endless originative potential for designing systematic graphical structures.

It is perhaps the most noteworthy component of *Arthur* which enables an instant evaluation of images being produced. The 'aesthetic signature' of a pattern is determined from the selection and arrangement of its symbols. The program enumerates over a dozen partial aesthetic functions diagnosing whether the design is disturbing or monotonous, what amount of information is assigned to individual symbols, what time is required to read the entire image, how much attractive the pattern can be considered, etc. Processes of the computer-driven creation and evaluation may be then iterated until particular settings of the aesthetic values are obtained. A synoptic evaluation of relatively complex patterns is presented in Figure 5.

A series of experiments has been performed recently to find out which of the implemented functions can be reliable predictors of a pattern attractiveness. Groups of probands were asked to decide aesthetic values of 96 sample images by providing a numerical feedback on an open-ended scale of positive integers. Results summarized in [7] indicate what information and structural qualities have proven to be relevant for establishing an aesthetic experience among the probands. To give at least a brief notion, subjects preferred images with higher order, lower entropy, and complexity oscillating around average values. For instance,





$H = 3.97\,\mathrm{b}$; $H_{\max} = 4.32\,\mathrm{b}$	$H = 3.63\,\mathrm{b}$; $H_{\max} = 4.32\,\mathrm{b}$
$I = 1586.32\,\mathrm{b}$; $I_{\max} = 1728.77\,\mathrm{b}$	$I = 1450.36\,\mathrm{b}$; $I_{\max} = 1728.77\,\mathrm{b}$
$I' = 198.29\,\mathrm{b\,s^{-1}}$	$I' = 181.29\,\mathrm{b\,s^{-1}}$
$t_{\min} = 99.15\,\mathrm{s}$	$t_{\min} = 90.65\,\mathrm{s}$
$R = 8.24\,\%$	$R = 16.10\,\%$
$O = 0.03$	$O = 2.35$
$T = 9.41$	$T = 11.13$
$C = 84.36$	$C = 74.01$
$L = 0.30$	$L = 26.18$

Figure 5: Examples of an algorithmic pattern evaluation ; depicted images reveal similar information characteristics but different structural qualities.

symmetrical images were largely considered as appealing (almost for sure when their complexity was high at the same time), but in cases when the redundancy stepped out of some threshold they lost their ability to meet requirements for truly engaging images. Asymmetric images were acknowledged only when their temperature and entropy were both above average values. The measure of life has proven to be the best aesthetic predictor for a given class of images. The most and least attractive patterns are overviewed in Figures 6 and 7 respectively.

5. Conclusion and Acknowledgements

Although the experiments were rather introductory, the results obtained thus far may already provide practical foundations for creating aesthetic filters in various computer-aided design applications. Employing algorithmic reasoning in aesthetic evaluation appears to be beneficial in communication graphics, interface design, virtual environment construction, architecture planning, and in the visual arts in general. More careful analysis of factors influencing "human understanding" of images, taking into account not only the *form* but the *meaning* of visual stimuli as well, is a subject of current research. My humble belief is that with a deliberate installation of computers into creative processes and their critical evaluation the visual side of our everyday lives may once be experienced as more enjoyable and perhaps less tiring.

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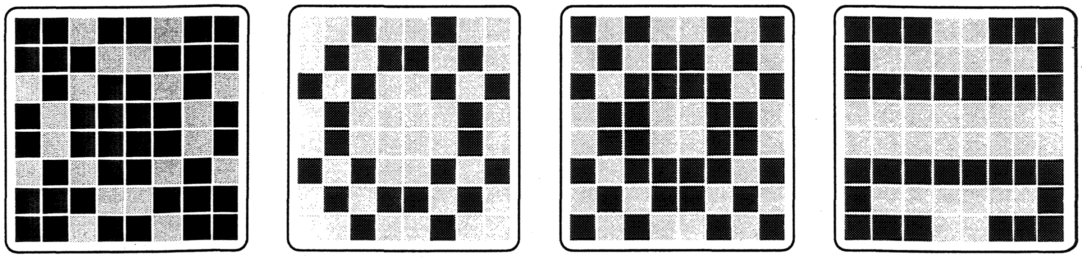

Figure 6: Mostly appreciated images with high values of life.

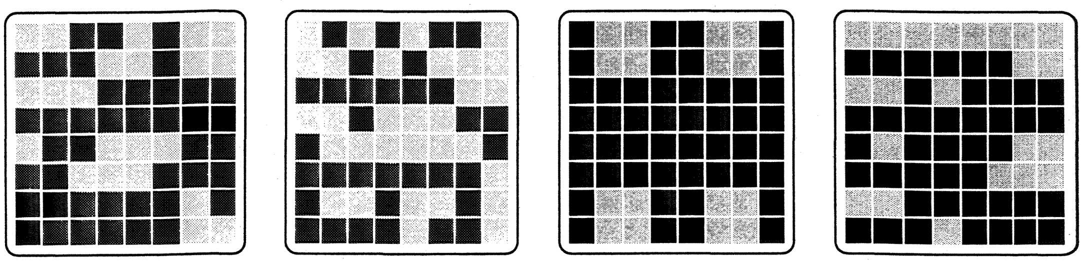

Figure 7: Images frequently discarded with substandard values of life.

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