Computational Aesthetics in Graphics, Visualization and Imaging (2005)
L. Neumann, M. Sbert, B. Gooch, W. Purgathofer (Editors)

# Defining Computational Aesthetics

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**Abstract**

*This paper attempts to define the discipline of Computational Aesthetics in the context of computer science, partly reflecting the contributions and comprehensive discussions of the first EG Workshop on Computational Aesthetics in Graphics, Visualization and Imaging. It points out the current problem of "aesthetic pollution" as a side effect of computer aided design and gives motivation to improve current computational methods by adding aesthetic awareness. An introduction on how this could be achieved is given, listing significant results of previous research. It turned out that there are factors of aesthetics such as complexity and order, that could add up to a working measure. For building a pragmatic view on such measures, very restrictive scenarios of application are given. To conclude, the major aspects of this new discipline are stressed. They are (1) developing computational methods for aesthetic decisions, (2) taking human perception into account and (3) focusing on aesthetics in form and particularly objects of design, in order to guarantee immediate application.*

Categories and Subject Descriptors (according to ACM CCS): I.0 [Computing Methodologies]: General

## 1. Introduction

**Figure 1:** *What makes us experience beauty? If we look closer at a photograph, it's more than the content that pleases the eye, even though it can be very strong.*

This article is meant as a motivation to introduce the concept of *computational aesthetics* and as an attempt to define this discipline. The definition is derived by digesting existing theories and opposing those methods and concepts to other disciplines, culling the computational essence. Hence, trying to situate the core into computer science, showing the necessary relations to relevant disciplines. Substantially, such definition is intended to inspire research and application development and to ease understanding of this new discipline. It is a necessary reduction since aesthetic research, when observed in retrospective, spread out and scattered in numerous directions and disciplines.

Finally, I will mention some possible application scenarios that spring from this discipline of *Computational Aesthetics*.

At this point, I wish to mention that this article was motivated by the comprehensive discussions at the first *EG Workshop on Computational Aesthetics in Graphics, Visualization and Imaging* as well as my personal interest and extensive research in the context of a thesis on the same topic.

The next section should make clear this interest and encourage research in this interdisciplinary field of research.

## 2. Motivation

Aesthetics has been discussed by philosophers for ages. Although the Greek origin of the word is αισθητικη, meaning "a perceiver", it is now widely accepted in almost any encyclopedia to be defined as "the philosophical study of beauty and taste". Kant had also described aesthetics as a reinforcing supplement to logic ideas or concepts [Kan90], hinting that objects are of *higher value* to us if they are beautiful (in addition to the value of meaning, such as demonstrated by figure 1).

In a similar fashion, aesthetics plays a major role in *design*, complementing *function* and improving the products value in many ways. This fact is commonly known and we experience this aesthetics in the every day usage of many design objects such as cars, furniture, consumer electronics and so on. Good aesthetic design supports our understanding of complex functional objects, unifies their perception in a socioeconomic context (e.g. commercials) and helps seamlessly integrating them into an environment (probably the best example would be architecture).

Now, heavy use of computer aided design and planning introduced some kind of uniformity in the aesthetics produced. It appears as implicit aesthetics, which was not planned or taken care of. This 'byproduct' of how functional design and planning is performed by computational tools can be widely observed in e.g. architecture, food packaging, leaflets, etc. and the number of objects produced by these tools grew enormously. Particularly, the Internet delivers a flood of media created by both private individuals and professionals who do not necessarily ensure *aesthetic design*. All of which leads to the phenomenon of *aesthetic pollution*.

Since it is unfeasible for several reasons (such as limited resources) to have dedicated aesthetic design everywhere, it offers the problem for computer science to improve software tools in such a way that they are also aware of aesthetics, even if there is no human (artist) involved. This introduces one major motivation for *computational aesthetics*.

Still, to understand aesthetic problems in a more general context, one must point out the differences between objects of design and objects of art. The latter differ from the former by the lack of functional requirements which allows for unconstrained aesthetic possibilities. In other words, there are no determined objective demands for their aesthetics, the freedom of art. For scientific research it makes no sense to bind this freedom in any way. That means for *computational aesthetics* it is incidental to focus on the more determined aspects. However, since objects of art are aesthetically more versatile, they offer more a explorative basis for analysis. Also, computer generated art has been a rather popular topic for scientists interested in aesthetic computation in history and present, likely because it has often turned out as the only testbed for developed aesthetic theories and measures.

On the bottom line, research should put emphasis on application and explore aesthetics in design problems, which most importantly offer immediate application. There are essential questions: Can we construct tools that assist with creating *beauty* as easily as they do now with purely functional development? Can we make machines aware of the aesthetics in a similar fashion as humans are?

## 3. Theory

In 1933, George David Birkhoff wrote the first quantitative theory of aesthetics in his book *Aesthetic Measure* [Bir33]. Since it involves computational methods, this work often regarded as the beginning of *Computational Aesthetics*. His work showed some interesting thoughts as well as a good explanation of an attempt to formalize aesthetic measure by $M = \frac{Order}{Complexity}$, which should describe this aesthetic relationship which is commonly known as the metaphor "unity in variety". In other words, it represents the *reward* one experiences, when putting effort by focusing attention (complexity) but then realizing a certain pleasant harmony (order).

Birkhoff himself couldn't really show convincing results in application of his measure. However, his ideas broke new ground for aesthetics research and was inherited by various researcher. For good coverage and references to those works, please see the historical summary by Gary Greenfield [Gre05], which is complementary to this article here.

Now, while these authors (mentioned by Greenfield) by themselves did not really develop a solid theory or methodology for *Computational Aesthetics*, they made clear some aspects of aesthetics, such as the concepts of *order* and *complexity*. These *components* could provide a measurable basis for aesthetics and the following subsections will present a digestion of such features from previous research.

### 3.1. Complexity

One factor towards quantification of aesthetics turned out to be complexity. It's relevance can become intuitively clear when looking at e.g. paintings and suddenly finding oneself reasoning about why we like or don't like it, using arguments about complexity.

To Birkhoff, complexity was the amount of effort the human brain has to put into processing of an object. An effort necessary for the experience of *aesthetic reward*. He measured it for example in the visual case, by counting polygon edges and vertices. However, his work is purely empirical and hardly represents how the human visual system perceives complexity in a scientific manner.

Then after Shannon complexity became a sophisticated measure in the theory of communication, there was hope to build more objective measures. A number of researchers wove aesthetic theories, using the term *information aesthetics*, trying to add up to Birkhoff's work a new approach towards complexity (for a summary of this movement see Frank and Franke [FF97]). To one of the advocates, Abraham Moles [Mol58], one essential factor of aesthetics experiences was *originality*. He used it synonymous to quantity of unpredictability, the *complexity* of a *signal* transmitted by the environment and received by the human perceptual system. The problem of this model measuring complexity gets obvious for example in the visual case, where bitmaps insufficiently represent elements of perception and entropy is not connected to perceived complexity on a macroscopic level.

In the context of aesthetics, remembering that it is about perception, these approaches towards complexity are useless and it seems a task to find new metrics based on human perception and test how they relate to perceived beauty.

### 3.2. Order

If aesthetics solely depended on perceived complexity, a plain white canvas would be the most beautiful and the pure visual *chaos* the ugliest picture (or vice versa). This is obviously untrue. Therefore, scientists have frequently used the term *order* in the course of finding explanations of when certain levels of complexity are more appealing.

In Birkhoff's aesthetics the role of order was to perceptually *reward* the effort of focusing attention on something complex. He assumed that there exist elements of order such as *symmetry*, *rhythm*, *repetition*, *contrast*, etc. which psychologically cause a positive tone of feeling, and also elements that cause negative tones, such as *ambiguity* or *undue repetition*.

To Moles [Mol58], the concept of order was represented by *redundancy*, which represents a perceiver's *a priori* knowledge of a received stimulus and keeps complexity down to an interesting or aesthetically pleasant level. More precisely he related order to the degree of predictability and internal coherence, expressed by the concept of *mean autocorrelation*. His contemporary Max Bense [Ben65,Ben69a,Ben69b] took Birkhoff's formula, using statistical redundancy in place of order, reasoning that it represents identifiability, the *known*. To him a creative process was an *ordering process*.

A more recent approach was done by Machado and Cardoso [MC98], who tried to apply *fractal image compressibility* as an element of order in their aesthetic measure, assuming that self-similarities can be more easily perceived. They follow a similar argumentation as Birkhoff, however using more recent and more complex methods of measuring. Similarly, Spehar et al. published paper called *Universal aesthetic of fractals* [SCNT03] showing a direct comparison of *fractal dimension* and human aesthetic preference. This demonstrates yet another measure of order in relation to aesthetics.

A more specific aspect of order is found in color research. Color perception is far from being trivial and further it is often regarded as one of the most important factors for aesthetics. Antal Nemcsics has developed a color order system named Coloroid [Nem80]. In essence, it is a color-space that is supposed to be uniform in aesthetic distances rather than in perceptual differences. This could allow measuring of color harmony, an element of visual order.

Additionally, empirical work on concepts of order (e.g. symmetry, equilibrium, rhythm, etc.) can be found in Arnheim's *Art and Visual Perception* [Arn74]. In this book he defined an analogy of visual patterns to physical systems and derived a set of laws, which are relevant to perception of art. His work is commonly taught in art classes and could be a guide for quantification of elements of order.

On the bottom line on can see that many authors put *order* into an important role in aesthetics, and is most of the time interpreted as an opposing force to *complexity*.

Research should focus on which measures of order show relevance for aesthetic measures.

### 3.3. Ergonomics

Another possible aspect of aesthetics is ergonomics. For understanding of this possible relationship, imagine the following example: The design of a chair can be fit to a person's body in such a way that it's designated purpose, sitting, is improved. Now the question raises, whether this idea can be realized analogously to human perception, measuring ergonomic properties of stimulus patterns in a similar fashion as measuring the chair. Is ergonomics then in any way a precondition to an aesthetic experience? In either case, a theory of *perceptual ergonomics* seems intuitively feasible and could possibly form another component for aesthetics measures. An article first mentioning ergonomics and aesthetics in the same context was done by Y. Liu [Liu03], proposing a new discipline named *engineering aesthetics*. However, the goal is to integrate aesthetic factors into ergonomics and not the other way round. Whether this relationship exists in both directions is subject to further research.

### 3.4. Learning

From human intuition, we can immediately agree that what we think is beautiful is connected to our experiences, i.e. what we have learned. One inspiring example would be listening to a song. Sometimes when hearing a particular song for the first time it can seem uninteresting and even unpleasant. After a few temporally distributed repetitions of hearing it, it suddenly becomes beautiful.

Is this a result of learning dynamics connected to aesthetic perception and can this be quantified? Or is this phenomenon simply attention related?

In Moles' information theoretical model of aesthetics, the concept of a memory represents the important role of influencing perceived redundancy and therefore also the quantity of aesthetic information. Following the fact that human memory (i.e. the repertoire of elements for communication) changes dynamically, he introduces the term *differential information*.

This raises an interesting question, whether aesthetic quantification can be found doing analysis of learning dynamics. A task which could be probably performed with *Machine Learning* algorithms, but this hasn't yet been subject to research.

## 4. Definition

In the last section, a summary of aesthetic theories and methods has filtered out some relevant concepts. The present section will now try to derive a definition and point out resulting problems.

### 4.1. Other Disciplines

Before *Computational Aesthetics* can be defined, it requires some clarification of how it currently overlaps with other

disciplines. Most importantly, there is the field of *Empirical Aesthetics* which is a subdiscipline of psychology and goes back to Gustav Theodor Fechner's *Vorschule der Aesthetik* [Fec76]. In 1965, the field's devotees founded the International Association of Empirical Aesthetics who's members regularly publish their results in the association's official journal, *Empirical Studies of the Arts*. Their methodology is in essence that of empirical psychology and their main aim is to apply these methods to collect data upon which aesthetic theories can be tested. This instantaneously offers an important source of research that helps evaluating any computational models of aesthetics.
Also, as mentioned earlier (3.2), the psychology of art (see Rudolf Arnheim) should be taken into account. It can provide ideas and also ways of evaluating developed methods.
Another obviously relevant discipline is Neuroscience, which did and will come up with more insight into the human perceptual systems, where objective aesthetics could possibly be found or justified. In general, the whole field of cognitive sciences must be considered and *Computational Aesthetics* as being part of it.
Ultimately, the relation to *Art* itself is of a different kind. On the one hand computer generated artworks can be and have been considered works of *Computational Aesthetics*. This happened mostly in *Evolutionary Art* research. On the other hand, the philosophical questions raised by the production of computed aesthetics are rather delicate and left open.

### 4.2. Computational Aesthetics

There are a lot of disciplines showing interest in aesthetics and research on most of the concepts mentioned in section 3 can be investigated using their methods. As a consequence of recently increasing interest of computer scientists in aesthetics, it is immanent to define the term *Computational Aesthetics* as a discipline of Computer Science, formulated as follows:

**Computational Aesthetics** is the research of computational methods that can make applicable aesthetic decisions in a similar fashion as humans can.

While this definition is yet very general, it emphasizes two major aspects. One is the use of computational methods and the other is the enhancement of applicability. Of course many researchers did follow the *holy grail* of universal aesthetic measures, but it seems appropriate to generally focus on very restricted situations of aesthetic decisions.
As a general approach, the concepts described in 3 should be taken as a collection of features which can be developed as measures, and integrated in order to test aesthetic relevance for a particular problem. Additionally, it is a task to refine this incomplete list and including new findings.
The next subsection points out some helpful restrictions to the above definition.

### 4.3. Restrictions and Limitations

Most importantly, on the path towards objectivity, it is very useful to reduce the focus to *form*, rather than to *content* and its associations to a person's mind and memories. Although from a psychophysiological viewpoint it is not completely clear whether this dichotomy can be made, it still seems widely accepted that aesthetic experiences can lie in both separately.
For example, it has been shown that certain visual features are processed pre-attentively in the human visual system [Tre85], which could form an objective basis for research of visual aesthetics. This also leads to another restriction that could be observed in recent works on *Computational Aesthetics*, the limitation to the visual case. This also reflects my interest and research and for that reason, from here onwards, the text will solely focus on visual problems.

### 4.4. Evaluation And Validity

One of the most significant challenges of any metric, method or algorithm dealing with aesthetics is its evaluation of the claimed validity. Aesthetics is assumed always to be subjective, but aesthetics choices can reflect the opinion of either (a) one person, (b) a group of persons or (c), a normalized observer that represents some kind of universal aesthetic opinion.
Measuring *one* person's aesthetic preference of a set of images can be done using various methods described by *Empirical Aesthetics*. This can be done easily.
Testing the validity of a metric such that is represents the aesthetic preference of a *group* of persons on the other hand is a more complex task.
On the extreme end, having a metric that claims *universality* or at least conformity to a common understanding of aesthetics seems nearly impossible. Further, people are not necessarily aware of the fact that they do have an aesthetic preference. How do we deal with this?
In any case, research of *Computational Aesthetics* should particularly make very clear *what* aesthetics is meant and who's preference it represents.

## 5. Towards Applications

Besides interest in a theoretical model in Computational Aesthetics, there is an important emphasis to be put on the application. One observed phenomenon is that computational tools are already going in the direction of an aesthetic user and task adaptation process, and not solely in a functional fashion. For example, in photo & imaging software there are already helpers like automatic contrast adjustment, scratch/dust removing and automatic color adjustment tools. While they are functional, they also work on artistic and aesthetic features of the object they produce and take human perceptual properties into account.
One pragmatic view would involve creating a wider range of

aesthetics- and perception-aware tools. Below there is a list of situations that offer potential improvements through the addition of aesthetics.

### 5.1. Rendering and Visualization

Precision in rendering turned out to be not suitable in certain scenarios of presentation. For example, a garden designer would come up with the latest photo-realistic visualization of his design suggestion to show to his customer. Once the business agreement is completed using this preview and the garden is laid out, people tend to criticize dissimilarities. Because the visualization came so close to reality, it automatically invites comparison.
The "aesthetics" or look-and-feel of a pencil sketch on the other hand creates more loose associations with the final product in the human mind. Customer's satisfaction turns out to be higher, so many craftsmen and artists prefer this style.
Another artistic field having it's own style and aesthetics respectively is *science illustration*. It's a very specific style that supports the way knowledge is effectively transported to the student. Breaking down visual complexity is one main aspect, but also guiding the observer's aesthetic associations in certain ways seems important.
Many styles of scientific illustration are results of highly complex artistic workflows and there is little computer support and formalism.
Now, to Computer Graphics from a *Computational Aesthetics* perspective, this hints towards a new aesthetics-oriented paradigm. This paradigm is to identify the targeted aesthetics first and choose the rendering style accordingly and develop supporting tools.

### 5.2. Stylization Techniques

In art history, the term *style* of an image is used as a classification of purely formal features like color, composition, painting techniques, etc. in the artist's temporal, social and cultural context. A painting's style is a legitimate cause of specific aesthetic experiences.
Towards a computational model of these associations and experiences there is a requirement for formal methods describing and synthesizing these styles. Again, from a *Computational Aesthetics* viewpoint, it can be said the resulting models would be sufficient, whenever they preserve the aesthetic associations they cause in the mind of the observer. Some examples of already existing methods are:

- Color Style Transfer, Synthesis and Evaluation
- Brush Stroke Synthesis
- Perspective/Viewpoint Selection
- Image Analogies
- Lighting Design

The word aesthetics is often confusingly used actually meaning *style*. For example, "the aesthetics of commercials". While this is basically wrong, it shows the strong relationship between those two concepts.

### 5.3. 3D Modeling

The extension of visual research to 3D modeling work-flows and tools should be also examined. One article attempting integration of artist's aesthetics in modeling tools was presented at WSCG'03 by Giannini [GM03]. The result was a free-form modeling software for the automotive design industry, assisting designers' aesthetics judgements.
Also, tools for sculptors in non design related artwork

**Figure 2:** *Sculpture by Tomàs Pons Cortés, showing complex forms resulting from complicated artistic workflows and several materials.*

could benefit from modeling tools which adapt to their aesthetic preferences and workflows. Forms resulting from such workflows can be very complex, as visible in figure 2. Now in reverse, it is of interest to learn from such artistic processes and integrate them back into design tools, extending existing free-form tools.
For *Computational Aesthetics*, extending research beyond two-dimensional imaging seems therefore attractive.

### 5.4. Generated Artworks

Finally, another rich area of research and a testbed for metrics of aesthetic features is (automatic) computer generated art. Rules that try to define a certain style and certain aesthetics are incorporated into *evolutionary algorithm* fitness functions and generate whatsoever media (generally images or music). For some references see [Gre05].

Even though research almost never involves an objective evaluation of such a system's output-aesthetics, it can be empirically tested with artists' judgment. At least in the freedom of the art world, this is sufficient.

### 5.5. What else?

Of course the application scenarios mentioned above are only an extract of many possible ideas. Aesthetic decisions take place in many areas, professions and every day life situations. To name a few more and inspire to think about applications: photography, architecture, interior design, landscape design, human computer interaction, layout design, content-based image retrieval, etc.

## 6. Conclusions

I have developed a definition of a new area of research in computer science, that could reflect recently observed interest of researchers in aesthetics. It was also motivated by the first *EG Workshop on Computational Aesthetics in Graphics, Visualization and Imaging* that set the same goal. It brought together computer scientists with artists and made a step towards awareness of aesthetics in many computer science disciplines.

Aesthetic research has been redefined in a new technological context during the previous century and new theoretical concepts were formed. I have sketched the essential concepts and pointed out their relevance for aesthetic quantification.

Also, on the path towards applications, emphasis was put on *objects of design* and their difference to *objects of art*, which lack of functional requirements. Most significantly research should focus on aesthetics in *form* rather than *content* and find objectivity in psychophysical models of human perception. In contrast, any pure theoretical outcome or reasoning about the values of *Art* is rather pointless, taking into account the philosophical problems one will encounter.

However, on the bottom line this new discipline seems justified and might catch increasing attention by researchers from now on.

## 7. Acknowledgements

I'd like to thank the participants of the 2005 *EG Workshop on Computational Aesthetics in Graphics, Visualization and Imaging* in Girona, Spain, who's thoughts and ideas are partly the basis for this paper. Especially I wish to thank those, who took the time and patience for helping with numerous questions.

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