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TERMS AND MEASURES FOR STYLING PROPERTIES

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1. Introduction

The definition of free form shapes for consumer appliances is the domain of stylists, designers and model makers who combine craftsmanship and the ability to communicate emotional qualities. Computer-aided techniques and tools like CAD and CAS systems get increasingly important to support the experts in their work within the process chain. Computer support for the creative phases is a very new development, and the smooth integration of styling into the product development process is still not sufficiently achieved. Curves and surfaces are usually given in parametric representations (mainly Bezier or NURBS) defined by a huge amount of mathematical parameters which lack clearness - especially for non-mathematical users. Improvements are needed, because communicating the original form and its design character throughout the process from early sketches to class-A quality has top priority.

During the process of product development the optimisation loops with milling, manual work on the physical model and surface reconstruction are very expensive. The FIORES project [Dankwort 2000] developed target driven automatic tools which solved several engineering in reverse (EiR) problems [Bosinco 1998]. The idea was to use derived features like highlight patterns which are checked to judge surface quality and design character as input data defining the optimisation goal.

In order to be able to judge whether the model still shows the intended design character and reaches the desired surface quality one needs measurement methods for the properties of those feature lines and evaluation curves. Within the optimisation routines of FIORES, a similarity measure has been used which comes up with reasonable results, but does not really comply with the stylist's understanding of which curves are similar or not. It was derived purely from the mathematical or technical point of view. In contrast to this, styling curves are judged very emotionally, depending on the context they are used in, which makes it difficult or even impossible to find the *one* similarity function to fit all needs. Several measures are needed for different aspects of the curves, and those aspects should be described in words familiar to the end users in a real application environment.

For this purpose a second project (FIORES II) was initiated to handle those emotional aspects and find mappings between verbal styling descriptions and engineering parameters. This paper intends to propose a reasonable terminology for styling features, properties and modifiers, and describe them mathematically. We will first specify the field of styling and the features and properties we want to formalise. Then a list of terms is presented describing features, properties and values used in styling applications. For selected terms a formal measure is proposed.

2. Styling properties

We will now isolate the kind of objects we want to investigate. When we call them "styling properties" we need to specify both parts of the term. As the term "styling" is often used almost synonymously with "design" a discrimination of these words and their meaning is needed. Without going into detail of any design theory or the different usage of the terms in various application fields we will stay with the following informal circumscriptions:

- ***Styling*** concentrates on modelling the outer appearance of a product. It uses emotional and aesthetic values and does not serve any technical or functional purpose.
- ***Design*** is the creative integration of technology, function and form.

Thus, if we look at styling properties, we only deal with the outer skin of a model and are not interested whether it stands for some technical of functional feature. Surely, styling usually supports functional aspects and the appearance must fit into the whole image of the product and its technical implementation, but in principle styling is free to do what ever it wants.

A model shows or carries features (see Figure 1). We do not want to step into the ongoing feature technology debate, so we follow one of the most open definitions of features given by the FEMEX group saying that features are "regions of interest" [Weber 1996]. Features can completely be described by their properties which then are specified by values. There exist very different kinds of features, properties and property values. Well known are all kinds of mechanical features which find their implementation mainly as parameterised macros in modern CAD systems (like drill holes). Apart from properties like material, constraints or process information those mechanical form features are described entirely by engineering properties which are those attributes that can be measured easily with numerical values, e.g. the length of a curve.

Things get more complicated as soon as we use free form geometry. First of all, one must decide which feature is meaningful for the design or style. A collection of those with a reasonable parameterisation can be found in [Fontana 1999]. Sometimes, derived properties are more important for checking the quality of the model than the explicitly given ones used for the model construction. This could be for example the volume for a mechanical part or the flow of reflection lines for a free form surface. One can discuss whether to call derived reflection lines (plane sections, curvature maps, ...) properties or features of the model, because on the one hand they are revealing properties of the underlying surface, but on the other hand they are lines, families of lines or colour maps for themselves which one would like to call features. We will use the term "styling feature" for derived and constructive free form features as long as they stand in connection with the aesthetic impression.

Describing free form curves and surfaces by their mathematical representation or their pure engineering parameters is essential for the later product definition and manufacturing steps, but not very convenient for using them in a styling environment where mathematics is regarded being a necessary evil (demanded by engineering devils). Stylists use different, more verbal and emotional descriptions to point out the character of curves and surfaces.

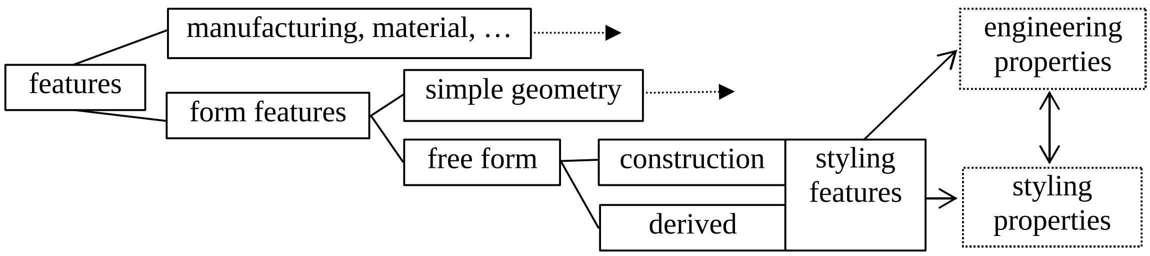

Figure 1. Hierarchy of features and properties. We focus on the relations on the right

During the different phases of the styling process (sketching, clay modelling, and CAS) styling features are verbally described by a set of properties we will call "styling properties". They also carry information about the technical quality (e.g. surface continuity, see [Hagen 1993]), but mainly about the aesthetic and sometimes emotional character of the model [Knoop 1998]. We are interested in how this information is named and communicated with styling properties, whether there is a mapping to engineering properties, and how we can use this mapping for formal measurements.

To say it clearly: We are not going to measure the beauty or the harmony of a model, but concentrate on measuring certain shape features which play a role in creating emotional effects.

3. Description and measurements of styling terms

3.1 Styling features

One word about styling features in contrast to styling properties. Application users do not distinguish exactly between these two categories. While terms like *step*, *corner, s-shaped* (or ogee [Burchard 1994]), and *break line*, do always describe features the terms *blending* and *radius* can be both, features and properties.
In engineering, a *radius* is the constant radius of a circle. In design, the term radius is much more generally used as being a somehow more rounded transition (a *blending*) between two curves and also surfaces. There is no need for a radius to be constant. When used as a property one can assign values to *radius*, either by using real numbers or verbal qualifiers. In the second sense a small radius can be called *sharp* and a big radius can be called *soft*, where the thresholds for small and big depend on the context (overall size of model, involved stylist, application field, etc.).

3.2 Styling properties

It follows a non-exhaustive list of terms which are used to communicate relevant properties of curves and surfaces. It was compiled by stylists, surface designers, and clay modellers from the FIORES-II consortium. Sometimes it is necessary to explain one term by another one and vice versa. This definitely is a circular dependence, but can hardly be avoided.
Following the descriptions of the styling terms we will also try to give proposals for the measurement of styling properties. Most of the measures are very simple and straight forward attempts to solve the problem of quantifying verbal expressions. They will definitely not always come up with reasonable results, and need to be refined in a real world application with styling end users. The figures are only given for explanatory reason. They are of no styling relevance.
One must always have in mind that the given measures are not meant to give unique or reasonable descriptive values for the particular properties. If a curve is 0.8 *straight*, the number does not mean that it is double as straight as a curve with straightness 0.4. The only conclusion we can draw from those values is, that the first curve is *more* straight than the second. For our intended application (which is to use optimisation algorithms for changing curve features to make them similar to a given target) this characteistic of the measures is sufficient, because knowing whether to be closer or not to a target means knowing whether a modification step was useful or not.

3.2.1 Straight / flat / curved

Used as an engineering term, a *straight* line is the shortest connection between two points which is a linear curve (in design line and curve are mainly used synonymously). A linear curve has zero curvature. This leads us to a design definition of the term straight: A *straight line* is a curve with infinite *radius*.
While in engineering a curve is either straight or not, for a designer the curve can be more or less straight, depending on how big the overall radius is. The bigger the radius, the more straight is the curve.

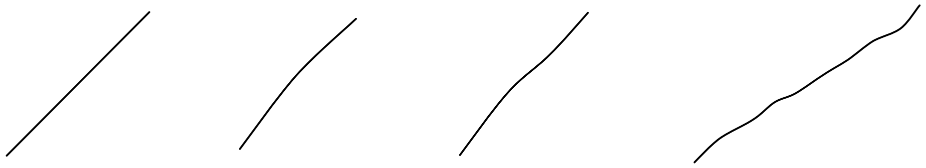

Figure 2. Examples for straight curves: Engineering, design, s-shaped, noisy (left to right)

Even *s-shaped* curves or wildly changing curves can appear straight, if the *straightness* of the curve dominates the (obviously) unwanted s-shaped character or the perturbation of the curve from average (see Figure 2). These curves can be called imperfect (for s-shaped) or trembling (for noisy curves).

Straightness could be measured by the ratio of maximum and minimum curve elongation, which is the width and the height of the curve's minimum-area encasing rectangle. In order to make the straightness range from 0 to 1 we use

$$\text{straightness} = 1 - d_{min} / d_{max} \tag{1}$$

For surfaces *flat* means more or less the same as *straight* for curves and the formal connection between them is very close. Surfaces can be called flat in one or two direction, if their main sections (or large portions of them) are straight curves. The term *curved* for lines (curves) is used as being the opposite of *straight.* For surfaces it could be seen as the opposite of *flat* respectively, but one prefers to use the term and concept of *crown* more often (see respective section).
In addition to the easy measurable kinds of straightness proposed, things can get very tricky if optical illusions are considered. So do rather straight long lines and flat large surfaces have the tendency to appear *hollow*. We will treat this problem in the section for *hollow*.

3.2.2 Sharp - Soft / Crisp / Hard / Crude

All these terms are used to describe transitions between curves or surfaces. In general, a (blending with a) small *radius* can be called *sharp,* and a (blending with a) big *radius* can be called *soft*. Giving absolute values for sharpness or softness is in most cases less important than giving the difference of two curves. Then, making a radius sharper (softer) means to decrease (increase) the radius of the blend. The meaning of "big" and "small" depends on the sizes and proportions of the curves to be connected. This has to be taken into account especially while working on scale models. Almost any property must be exaggerated there in order to achieve the same effects as in the full size model.
Crisp is another word for *sharp* which is especially used for characterizing edges and corners. One can model a 90° corner to look more crisp by using a negative *lead in* (see respective section) such that the corner angle is less than 90° (see Figure 3).

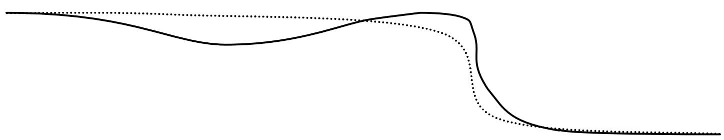

Figure 3. Applying a negative lead in to make a corner look more crisp

Hard and *crude* are terms describing an abrupt change (of curvature evolution). The transition between two curves / surfaces can look hard if there is not enough *lead in* between curve and radius.
When we give measures we will concentrate on the minimum radius of a given blending curve and say that a *sharp radius* is a small radius, while a *soft radius* is a big one. Thus, we get something like

$$\text{softness} = \text{radius}_{min} = 1 / \text{sharpness} \tag{2}$$

While for crisp, hard and crude we propose the same measure as for sharp:

$$\text{crispness} = \text{hardness} = \text{crudeness} = \text{sharpness} \tag{3}$$

This equality may appear too general. One should set *hard* in relation to the context, because the "non-harder" or softer (or sometimes straighter) the environment of the transition the harder we can call the same sharp radius. Thus we could use something like

$$\text{hardness} = \text{sharpness (blending)} / \text{softness (base curve or surface)} \tag{4}$$

3.2.3 Convex / concave

A curve is *convex* or *concave*, if the curvature along the curve has the same sign. Whether a curve is convex or concave depends on the context in which the curve is viewed. Within closed contours or closed bodies the convex and concave curves and surfaces can easily be named as the ones bending to the outside or inside respectively. If there is no body or closed contour to relate to, one has two main possibilities to decide between convex and concave. If the curve under investigation is a part of a bigger contour, one usually judges its relation to the overall tendency of the contour. If the curve stands on its own or the overall tendency of a non-closed contour shall be judged, we can relate it to the "natural directions" which are from bottom to top and from left to right (see Figure 4). If the curve follows these directions we can call it convex, otherwise concave.

Things get more easy if a curve is already named. Then, making a curve more convex (concave) means to increase (decrease) the curviness of the curve which is to increase (decrease) the area or volume of the enclosed figure or part.

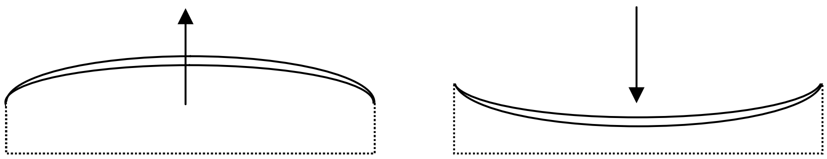

Figure 4. Increasing convexity and concavity with respect to the bottom to top direction

For a measurement one could simply define convexity and concavity as signed curviness, where the sign must be derived from the viewing perspective or the object itself, maybe by its barycentre. Another possibility is to use the signed area under the curve (limited by the line between the two curve end points) as a measure for convexity/concavity. One could even combine both ideas by using their product

$$\text{convexity} = \text{signed area} * (1 - \text{straightness}) \tag{5}$$

where positive values stand for convex and negative ones for concave. For 3D objects we replace the arc area by the enclosed volume of the surface and the curviness by the *crown*.

3.2.4 Hollow

A property very close to convexity is *hollowness* which is a less technical but more subjective concept. From the engineering point of view a curve or surface can be called *hollow*, if it is *concave*. In design a curve or surface can look hollow by wish or by mistake although it is not *concave* at all. If for example an almost *straight* curve is connected to a rather small almost true radius, the connection usually appears hollow, because there is no smooth *lead in*. The observer follows with his eyes the *radius* evolution which would create a truly *concave* transition. As a consequence a curve may appear more straight if it is more curved - or has some *crown*. The ancient Greek already knew about such kinds of effects and avoided long straight horizontal lines on their temples. In order to not make them look hollow they built the horizontal parts slightly *convex*.

Thus, giving a measure for hollowness may be difficult. Hollow is very close to concave, but parts can appear hollow even if they are not concave at all. It seems to be necessary to involve the curve's orientation in space which can be seen in the fact that long horizontal lines are often judged as being hollow:

$$\text{hollowness} = \text{concavity} * \text{arc length} * \text{horizontality} \tag{6}$$

where *horizontality* is the cosine of the elevation angle for the whole curve (e.g. the connection line between start and end point) with the x-axis.

3.2.5 Crown

Although crown sounds like being a feature only and not a property, the term is used mainly as a modifier like in the phrase "Put on *more crown*". It means lifting or raising a certain part of the curve or surface, but not changing the end points or edges. In principle, one can raise every kind of curve, but "putting on crown" can only be applied to already *convex* curves.
There are different parts of curves and surfaces which can be given more crown, and crown is always added into a certain implicitly or explicitly given direction. Parts and directions are defined by certain base lines or sections of the curve, and the crown is added perpendicular to them (see Figure 5):

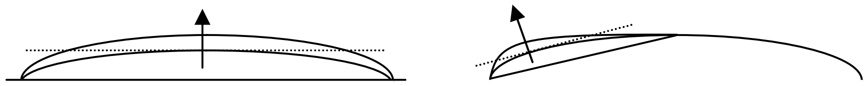

Figure 5. Different possibilities to add crown

(A) The base line is the connection between start and end point of the curve. In this case the curve gets some kind of raised (mainly for symmetric curves).
(B) The base line connects two important points, such as end points, inflection points or *flat* points, or just points "where the *acceleration* starts". Then the curve gets pushed at its biggest elongation point into the direction perpendicular to the base line (mainly for asymmetric curves).
Crown could be measured simply by the maximum elevation of a curve with respect to a chosen base line. This base line could be the x-axis or the connection between start and end point or - the connection between two important (user-chosen) points.

3.2.6 Acceleration

Acceleration is a term used to describe curves with rising curvature. A curve without any acceleration is a true radius. Fast or slow acceleration means that the curvature increases fast / slowly. If a curve changes curvature slowly it may show no acceleration at all. There is no unique definition of when a curve starts accelerating, but acceleration always starts in a rather *flat* area and leads into a high curvature region (a *radius*, see also *lead in*). One could define a measure for acceleration by the ratio of curvature difference and arc length *l* where the difference happens:

$$\text{acceleration} = Dk / Dl \qquad (7)$$

The degree of acceleration in one point can then just be given by the rate of curvature change (the third derivative of the curve parameterised in arc length). The higher the change the more acceleration.

3.2.7 Tension

Tension can be understood from the physical analogy of applying tension to a steel spline. In the physical example the tension of the curve (or the bending energy) can be found where the curvature is highest. There are two ways to add more tension to a curve (see Figure 6):
(A) Keep the end parts unchanged and *flatten* the middle part (clay modelling view), which is analogous to fixing the ends of the spline and apply pressure on the middle part.
(B) Keep the middle part unchanged and increase the *radius* close to the end points, which means to hold the spline in both hands and turn the hands to the outside.
One can feel tension only if "something happens" in the curve, which means that there is an evolution of curvature along the curve. A first attempt for measuring tension would be the ratio of curvature extremes, but in order to be more global one could set the curvature difference in relation to the average curvature:

$$tension = (k_{max} - k_{min}) / k_{avg} \qquad (8)$$

As "tense" curves show specific amounts of *crown* one could also try to model tension by either crown in vertical direction (related to the base line) or crown in "diagonal" direction (related to a section line between two important curve points).

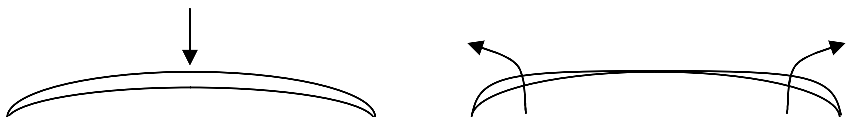

Figure 6. Two ways of applying pressure to get more tension

3.2.8 Lead in

As for most of the styling work it also helps understanding the term *lead in* by knowing how clay modellers proceed in their work of creating an object (see also [Yamada 1993]). They start creating the main surfaces from true sweeps (constant radius templates) and connect them by blendings - or a *radius*, as they would call it. In most cases, a constant radius connects to a curve only G1-continuous (tangent). Thus, this *hard* connection does not lead well into the transition. The curve or surface needs to be modified so that it smoothly leads into the radius and, thus, look harmonic. If "more lead in" is wanted we can do it in several ways (see Figure 7):
(A) Keep the maximum elongation point of the old blend and start the new blend more early
(B) Decrease the elongation of the old blend and start the new blend more early
(C) Keep the end points of the old blend and extend the elongation

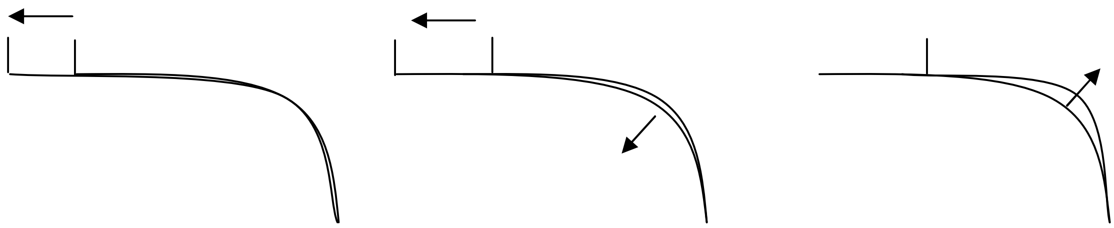

Figure 7. Alternatives for creating more lead in

Finding the lead in faces some special difficulties when seeking blendings between *convex* and *concave* curves. In these cases the curves to be blended should already carry the information that they tend to change direction, i.e. if we extend the curves by rendering their functions with parameters greater than 1, they should become *s-shaped*. This character must already be carried within the evolution of the curve's curvature and its derivatives. Another speciality is that one can give a negative lead in in order to make a corner look more *crisp* (see chapter for *crisp*).

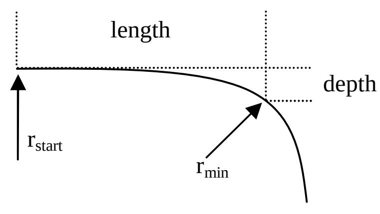

Figure 8. Lead in parameters

Starting with a true radius blending a lead in could be characterized by two parameters (see Figure 8): How much of the main curve do we cut away until we reach the minimum radius (*lead in length*) and how deep under the curve will we be then (*lead in depth*). Those two parameters can be measured independently from each other, but the length is the more important one.
We should try to include also the radius change (the difference of the radius at start of the blending and the minimum blending radius) such that we yield a measure which is less dependent of the actual size of the model:

$$\text{lead in} = \text{length} / (\text{radius}_{start} - \text{radius}_{min}) \tag{9}$$

4. Conclusion

We collected a list with terms for model features and their properties used in styling work, but the list is not a lexicon for styling. It is neither complete nor do stylists use all the concepts presented. In addition to this, each application area puts emphasis on different concepts. Nevertheless, all stylists, designers and model makers within the FIORES-II project agreed in the list to be reasonable, even though they come from four countries and work in different styling applications like automotive and consumer appliance industries.
Although styling is a very creative field of work few terms are sufficient to communicate design intentions. There *is* something like a common language. The language is not unique, but allows to describe changes to the model. The terms found can formally be described and measured. The proposed measures seem suitable such that it is possible to use them in optimisation algorithms, but they will need to be improved for their final application by additional field surveys. This paper shows: Beauty, appeal, and attraction may not be measurable, but styling properties are!

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