Towards an automatic semantic annotation of car aesthetics

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Abstract

The design of a new car is guided by a set of directives indicating the target market and specific engineering and aesthetic constraints, which may include also the preservation of the company brand identity or the restyling of products already on the market.
When creating a new product designers are used to evaluating other existing products to take inspiration or to possibly reuse successful solutions. In the perspective of an optimised styling workflow a great benefit could come from the opportunity of easily retrieving the related documentation and existing digital models both from internal and external repositories. In fact, the rapid growth of the web contents and the widely spread adoption of computer-assisted design tools have made a huge amount of digital data available, whose exploitation could be improved by more selective retrieval methods. In particular, the retrieval of aesthetic elements may help designers to more efficiently create digital models conforming to specific styling properties. The aim of the research described in this document is the definition of a framework able to support a (semi-) automatic extraction of semantic data from 3D models and other multimedia data to allow car designers to reuse knowledge and design solutions within the styling department. The first objective is then capturing and structuring both the explicit and implicit elements that contribute to the car aesthetics and can be realistically tackled through computational models and methods. The second step is the definition of a system architecture able to transfer such semantics through an automatic annotation of car models.

Keywords: Car styling, Shape semantics, Knowledge management, Geometric reasoning

1. Introduction

The development of a new car is a long and complex process due to the high number of aspects to consider and to the multidisciplinary expertise required, ranging from engineering to artistic and economical fields, and consequently the collaboration of several actors; in this scenario it becomes crucial to enable the information exchange among the people involved all over the design cycle. In particular, the increasing importance of aesthetic appearance strengthens the need of studying those product elements that have a specific meaning directly connected to the styling intent in order to share specific information concerning the product from an aesthetic point of view. The capability of capturing and maintaining the semantic information embedded in the product shape may allow car designer to easily retrieve documents and existing digital models both from internal and external repositories, thus making possible to reuse knowledge and design solutions. Today the availability of powerful and flexible knowledge technologies that are semantic-based and context-aware, facilitate the creation and the access to digital repositories; on the other hand, currently available knowledge-based systems focus on the functional elements of the design and do not support the management of the aesthetic knowledge.

Semantics stored in a digital encoding of a 3D model is inherently implicit, and it has to be extracted from shapes by dedicated algorithms. Unfortunately, today's state of the art shape matching systems (e.g. Osada et al., 2001, Kazhdan et al., 2003 and Novotni and Klein, 2003) are not accurate enough to distinguish between objects which have a similar overall shape or have mostly subtle differences, since they target the retrieval and classification of generic objects from the web. However, there are dedicated systems which were designed for the geometrical analysis in very specific domains (e.g. Razdan et al., 2001, Razdan et al., 2002) and therefore the algorithms can rely on domain knowledge to achieve better results. Domain knowledge has been considered to align objects for better analysis and to compare medical images (Krell et al., 1997), bones (Razdan et al., 2002) and archaeological artifacts (Razdan et al., 2001). Semantics inferred from certain geometric features of the object were considered in Corney et al. (2002), but without taking into account the context of the objects. Körtgen et al (2003) consider matching feature points inferred from geometry to establish context alignment. De Luca et al. (2005) formalise primitives and features of ancient architectural styles analysing architectural treaties, and they developed a knowledge-based modelling tool that shows stylistic references to the designer. Wielinga et al. (2001) developed a content-based image retrieval (CBIR) system for images of artifacts, which is based on an ontology of art styles derived from the Art and Architecture Thesaurus (AAT, 2005). Hernádvőlgyi et al. (2004) uses domain knowledge for aligning and comparing CAD models of cars exploiting knowledge about the fix arrangement of their components in the space. In CAD models, in fact, components are explicitly isolated, and to infer the context a correspondence has to be established between differently named but logically equivalent elements. This is a typical Knowledge Management problem, which requires an ontology that encodes knowledge about the design element.

Concerning the formalisation of style in the car design context, McCormack et al. (2004) define shape grammars to translate the key elements of the Buick vehicle brand into a repeatable language, which can be used to generate products consistent with the brand. It focuses on, and it is limited to, the 2D curves of the front view of Buick, whose elements and shape characteristics are then captured in a shape grammar made up by two classes of rules for the curve creation and modification. Hsiao and Wang (1998) presented a method for modifying the rough model of a car according to a wished character. To establish the

relationships between the character expressed in words and the shape they used membership functions of a fuzzy set and a multidimensional perceptual space using a multidimensional scaling (MDS) method. This approach is based mainly on the collection of customer verbal descriptions and only relies on the car proportions such as height, tail length.
The problem of identifying and using global features related to the car character has been faced also by Yanagisawa and Fukuda (2004), who defined a computer-based system for the appraisal communication of the customer to the provided model. Through repeated processes of shape proposal and score attribution the system should be able to provide a model that best fit with the customer preferences. It uses reduct methods for comparing the group of selected models with the discarded ones. Such a method considers the side view of the car and a refined version of the curve property values defined in Podehl (2002). Such properties, initially specified within the FIORES-II project (FIORES-II) and then refined in Giannini et al. (2004), are also used in the formalisation presented here and are then recalled in section 4.3.
The objective of the research presented in this paper is to define a framework architecture of a knowledge management system able to automatically or semi-automatically extract and store shape semantics during the concept modelling phase, and concurrently allowing designers to reuse aesthetic knowledge by accessing multimedia content and past design solutions; to this aim the first step is the identification of the main visual elements, and their relationships, that contribute to the car aesthetics, whose formalisation will constitute a specific domain ontology.
After a short overview of the concept design process given in section 2, the framework of the knowledge based system we propose will be described in section 3. Section 4 will focus on the formalisation of the car aesthetics. Section 5 will conclude the paper with the final remarks and future work.

2. The concept design process

To identify the basic elements of the car aesthetics and to evaluate their relevance, we have firstly to consider the process that brings to their definition.
When the development of a new car starts, the designer receives a *briefing*, which is a document folder specifying the new product in terms of ergonomics, basic engineering and packaging constraints, performances, target customer, cost and quality, often compared to competitor products. The final product should also confirm general norms and traditions, such as brand books, brand heritage, and general trends.
Marketing briefs insist mainly on the so-called *target*, i.e. the target customer category. Most car designers tend to use it as a general indication, with rather broad aesthetic relevance. On the other hand, the “package” defining measurements and proportions among parts has strong implications on the car aesthetics; for instance, long overhangs are considered typical of luxury cars, while, on the contrary, wheels pushed at the corners are typical of city cars. In addition, some companies preserve permanent shape characteristics in their products named *brand identity*; sometimes the brand identity is very general and derive from some proportions, sometimes it is very specific and depends on a particular shape of the roof line, the glass line, or of the front grille for example.
The best results in the process design come out when all the constraints are considered together from the beginning of the design process and all the issues involved are identified in order to make the most acceptable compromises. In fact, for a sports car the emphasis is on aesthetics and performance, whilst for a family car usability is more important even if it has also to show aesthetic appeal.

At the conceptual stage, sketches, excerpts from newspapers and magazines, pictures, blueprints, 3D models and videos are for designers the main sources of inspiration and means of communication of design ideas. In fact, stylists prefer conceiving a new product by sketching some essential curves, considered an abstraction of the product model; these are not only structural lines, like profiles, but also meaningful lines strongly affecting the product impression. These curves are usually referred to as *character lines*. Usually designers concentrate on profiles, or side views, and use perspective views for a global impression (Catalano et al., 2002).

In the early design phase changes occur frequently, since synthesis between the stylist's idea and the engineering and ergonomic constraints is not often immediate. When the final sketch is selected, designers present their project in the form of hand made sketches and/or digital drawings and often also rough foam prototypes; then, the creation of the *3D digital model* begins. The 3D model is normally created starting from those 2D curves used by the designer in the early conceptual phase and corresponding to the profiles and character lines. This is often not an easy task, since some characteristic elements are exaggerated in the sketch to enforce the desired effect. Typically, the selected hand-made sketch is scanned and converted into a digital format, and then used as a framework on which to build up, step by step, the different surfaces. The person in charge of creating the digital model is not usually the designer, but an expert in the Computer Aided Styling (CAS) tool, i.e. the *surfacer*; this person is very often familiar also with physical modelling, e.g. clay modelling, since such a skill is valuable for the sketch interpretation and shares similar terminology (Yamada, 1997). His/her main task is to create a precise mathematical model corresponding as much as possible to the drawn object. Therefore, during this activity, the stylists' help is required to perform the right shape adjustments: in this phase stylists communicate how to achieve their aesthetic intent using a special set of terms different from those used during the briefing.

In FIORES-II the language used during the early design phase has been deeply analysed (Poitou, 2002). It emerged that the language used when marketing people and stylists communicate is composed of terms that are related to emotional values (e.g. dynamic, aggressive) and express the generic objectives, i.e. the character the final product will hold. These terms have a contextual value since they are conditioned by fashion, trends, agreeability, attractiveness and other aspects, which are recognisable and coherently understood only within specific cultural and temporal conditions. Differently, during the creation and modification of the digital model stylists communicate how to achieve their aesthetic intent using a detailed and restricted set of terms, named *aesthetic properties*. In this phase, they provide instructions on which elements and properties have to be changed to obtain a certain effect (e.g. making a curve more accelerated, or decreasing the tension of a curve) and prefer not to use the geometry language, hardly intuitive for non mathematicians. In the project major attention has been put on the second language, while in this paper we will try to formalise part of the first language and cope it with the second in a unique framework.

Nowadays Virtual and Augmented Reality technologies cannot be ignored since offering stylists and designers the possibility to sketch and model more intuitively in 3D and in real time, and even to use real and virtual objects as visual reference thus reducing the need for physical prototyping. 3D input and output devices together with form-descriptive gestures (to sketch and to deform models three-dimensionally) have the potential to be much more effective than the traditional drawing methods since they allow easy and immersive creation and interaction with three-dimensional surfaces and their direct manipulation in 3D (Ucelli et al., 2005). Thus, including the digital outcome of such technologies in our framework becomes a natural evolution of the modelling flexibility.

3. Framework Architecture

The framework described in this paper provides a formalisation of the various aspects that designers reckon influence the aesthetic evaluation of a vehicle shape. Here the focus is the classification and specification of the various aspects and of specific aesthetics features of the automotive domain. This domain knowledge has been included in an annotation framework that supports the automatic extraction of semantic meta-data from models and images. The work is framed within a multimedia content retrieval system prototype, whose specification and detailed description are given in Ucelli et al. (2005) and Brunetti et al. (2005). The system aims at supporting designers in reusing knowledge, multimedia content and design solutions within the styling department. The availability of a formal representation of aesthetic knowledge will allow designers that are interfaced with the retrieval system from CAS and VR styling environments to enjoy a structured approach towards the retrieval of car aesthetics, and lately, brand identity elements.

The general architecture of the annotation framework, as shown in Figure 1, relies extensively on the domain knowledge for the automatic annotation process, through the ***Car Aesthetics Ontology***. The main aspects that have been identified as relevant in the aesthetic evaluation are: car categories, aesthetic character lines, aesthetic properties and relations among features, and characters.

Designers working on CAD/VR files produce models containing manual or voice annotations, which can be used as initial information and input for further analysis of the resources. CAD files embed at least car parts labelling, and VR files may be also enriched of voice annotations. These resources are analysed by Geometric Reasoning (GR) and Image Processing (IP) tools guided by the car aesthetics ontology in order to evaluate first which car category the resource belongs to, thus gaining initial hints about the character of the car; secondly, through the bridges between aesthetic concepts allowed by the domain knowledge formalisation, these tools extract and evaluate key lines, their properties and relations, and the final character. During this process GR and IP tools secure automatic annotations by providing algorithms specialised in the analysis of specific aesthetic aspects, and through the guidance of the domain formalisation that provides the contextual conditions for the analysis and evaluations of the character.

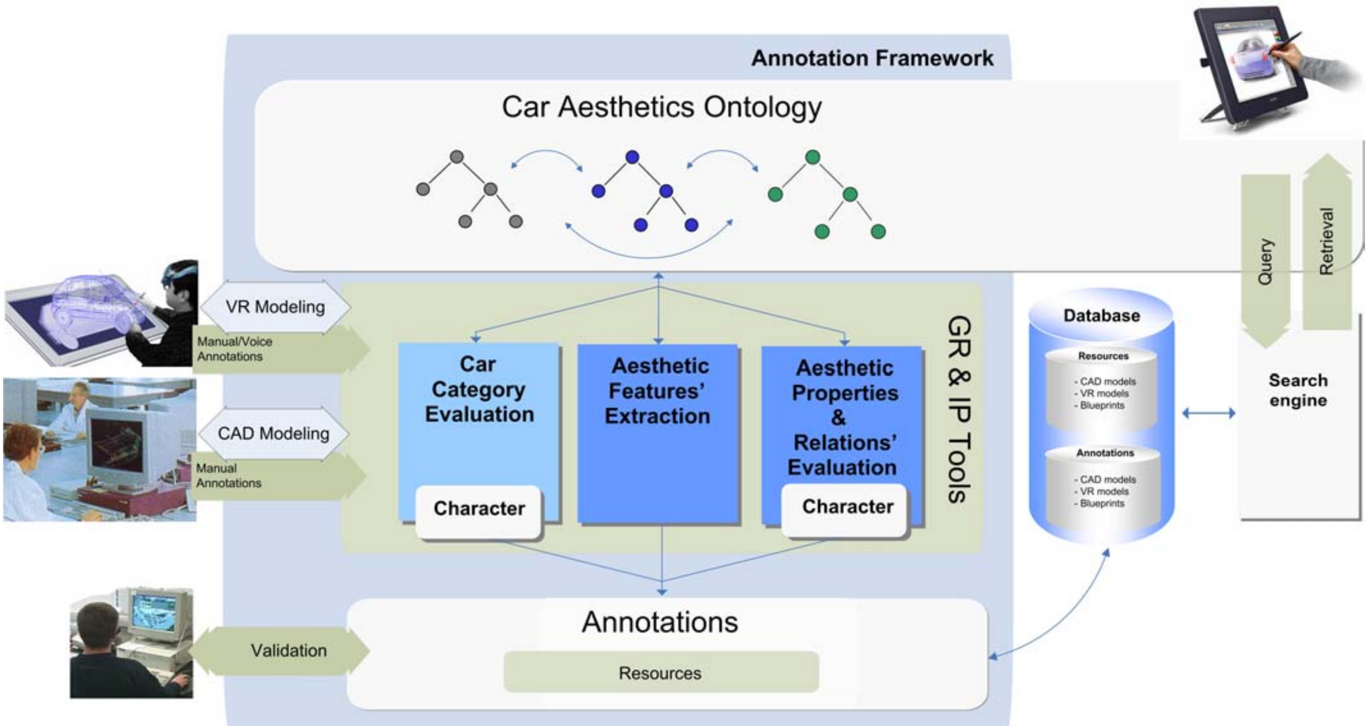

Figure 1. The Framework for annotating and reusing the car aesthetics knowledge

Annotations resulting from the automatic process are then validated manually by a domain expert (designer, surfacer, CAD expert) before being stored on databases with their content. The content retrieval system (Ucelli et al., 2005), which has been only generically described on the right hand side of Figure 1, is based on a Content Storage System (i.e. the database in figure), which stores content files and their annotations in the file system and databases.
The Search Engine handles the queries to the system, and the retrieval process for annotations and resources, also using the interface offered by the car aesthetics ontology. Finally, designers working on definitions of shapes for new products in CAD and VR environments can interact with the system for reusing aesthetic features according to the character of the car, and for seeking guidance by the system, which has an automatic understanding of the design context and early styling choices.
The next section introduces the concepts and properties of car categories, aesthetic features and characters that have been taken into account in the formalisation of car aesthetics for the annotation framework.

4. Formalisation of Car Aesthetics

There are some aspects playing a decisive role in judging a car: the first is called ***graphics***, and includes some details (e.g. spoilers, lights), the materials and the colour; the second is ***treatment***, which is the set of the surface properties including character lines which have aesthetic relevance; the last is ***volume***, i.e proportions and the mass distribution. Ordinary people perceive the car taking into account the mentioned aspects exactly in that order; on the contrary, designers develop their ideas according to the opposite order: at first, they define the volume, then draw the character lines and only in the end care about details.
The volume identifies the category of the car, in fact, it is defined by the proportions and some special ratios. Then, it will be adjusted or emphasised by the treatment, which will fix more clearly the character; finally, graphics completes and harmonises the global appearance (Catalano, 2004).

In the conceived *Car Aesthetics Ontology* the following classes have been defined at the root of the graph, as illustrated in Figure 2.

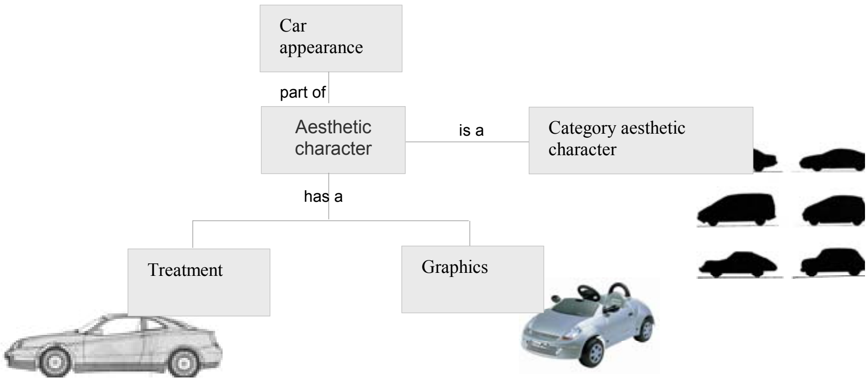

Figure 2. The Car Aesthetics Ontology (root classes)

In fact, each car has different aesthetic characters, but in general one or two are predominant. If it were possible to *measure* the aesthetic character of a car, we could formally say that:

$$\textbf{\textit{Global Appearance}}(car_x)=\langle ac_1(car_x, category(car_x)),\ldots, ac_n(car_x, category(car_x))\rangle\ \forall car_x,$$

i.e a n-uple of different basic aesthetic characters, where each ac_i has a value measuring the incidence of that character on a specific car_x. Since each character depends on the category of the car, the role and the importance played by the elements and their relationships are different according to the type of car considered.
In the next, we will consider the following subset of *Aesthetic Characters*

$$AC=\{sportiveness,\ dynamism,\ elegance,\ aggressiveness,\ friendliness,\ stability\},$$

derived from an analysis of marketing documentation and from discussions held with stylists of European car builders, such as Pininfarina, BMW and SAAB (Fiores-II).
The characters of *AC* apply differently to different category of cars. Then, as summed up in Table 1, there are categories which are candidates to have some properties. This only means that these categories generally have such basic aesthetic characters as predominant:

$$(\forall car_x \in category(car_x)\ \exists i\ ac_i(car_x, category(car_x))>0) \wedge$$
$$\wedge\ (\forall i,j\ ac_j(car_x, category(car_x)) \leq ac_i(car_x, category(car_x))).$$

Basic Aesthetic Character	**(Macro) Car Category candidate**
Sportiveness	Sports car
Dynamism	Sedan, Sports car
Elegance	Sedan
Aggressiveness	Sports car
Friendliness	City car
Stability	All

Table 1. Basic aesthetic characters and car category candidates

In the conceptualisation discussed further in subsection 4.3, a concept of measure is implicit, but it is not defined; analogously, the mentioned relationships and implications cannot be considered always true, but generally true. Our proposal reflects the shared knowledge we captured from stylists' experience. Moreover, the global appearance of a product is also conditioned by subjectivity, culture, fashion and, more important, it is not simply the sum of the single characterising element, but it is a much more complex combination. For these reasons, our goal is to make some tendencies explicit such that they can be used as filters in a framework for retrieving car models from an aesthetics perspective. Selecting the most probable entities concurring to define the style moves into the direction of the automation of such a process. Due to the intrinsic ambiguity and vagueness of the aesthetic domain, developing a framework for completely automatic annotation is impracticable. Adopting a reasoner which performs inference basing on a non monotonic logic may be a suitable solution. Non monotonic logics were born to handle the human reasoning with a formal language, which often takes decisions with incomplete, inconsistent and time-variable information. Different approaches have been proposed for a *defeasible inference*, such as default and abductive logics, and they are widely adopted in Artificial Intelligence and database applications.

Similarly, measures either of aesthetic properties, thresholds or ranges of validity will not be quantified in this paper, but only indicated where necessary. Some work has been started (Giannini et al., 2004), but it needs the analysis of larger number of car models for the evaluation of the identified properties and relations to validate the threshold values introduced.

4.1 Car Categories

The identification of the type of a car can provide the first indication of its aspect. We identified the main categories following the indications of the standard ISO 3833:1977 on types of road vehicles, and the common market categorisation. Limiting our study to only passenger cars the following main categories have been identified: *Sedan, Sports car, City car, Station wagon, Space wagon, Sport Utility Vehicle (S.U.V.), All terrain vehicle, Pick-up, and Limousine.*

Figure 3 illustrates a part of the car ontology we defined, showing the main categories in terms of individual classes, and their sub classes, with distinctive properties, together with car parts that belong to specific car types, and concepts related with car volumes (e.g. two-box, three-box car), which are strongly related with car categories. The root class *Car* has as properties the generic components that are present in all types of cars (e.g. hood, left_door, right_door_window), which all categories of cars inherit through the *is-a* relation with the root class. Some classes have multiple parental relations and inherit characteristics from multiple classes, for instance a *Targa* inherits properties from *Cabriolet* and *Roadster*. Higher level concepts such as *Family car*, which are not shown in Figure 3, are usually more ambiguous and they have been included as individual classes. The main categories, in this example, *Sedan* and *Station Wagon* are linked to concepts as *Family car* through axioms.

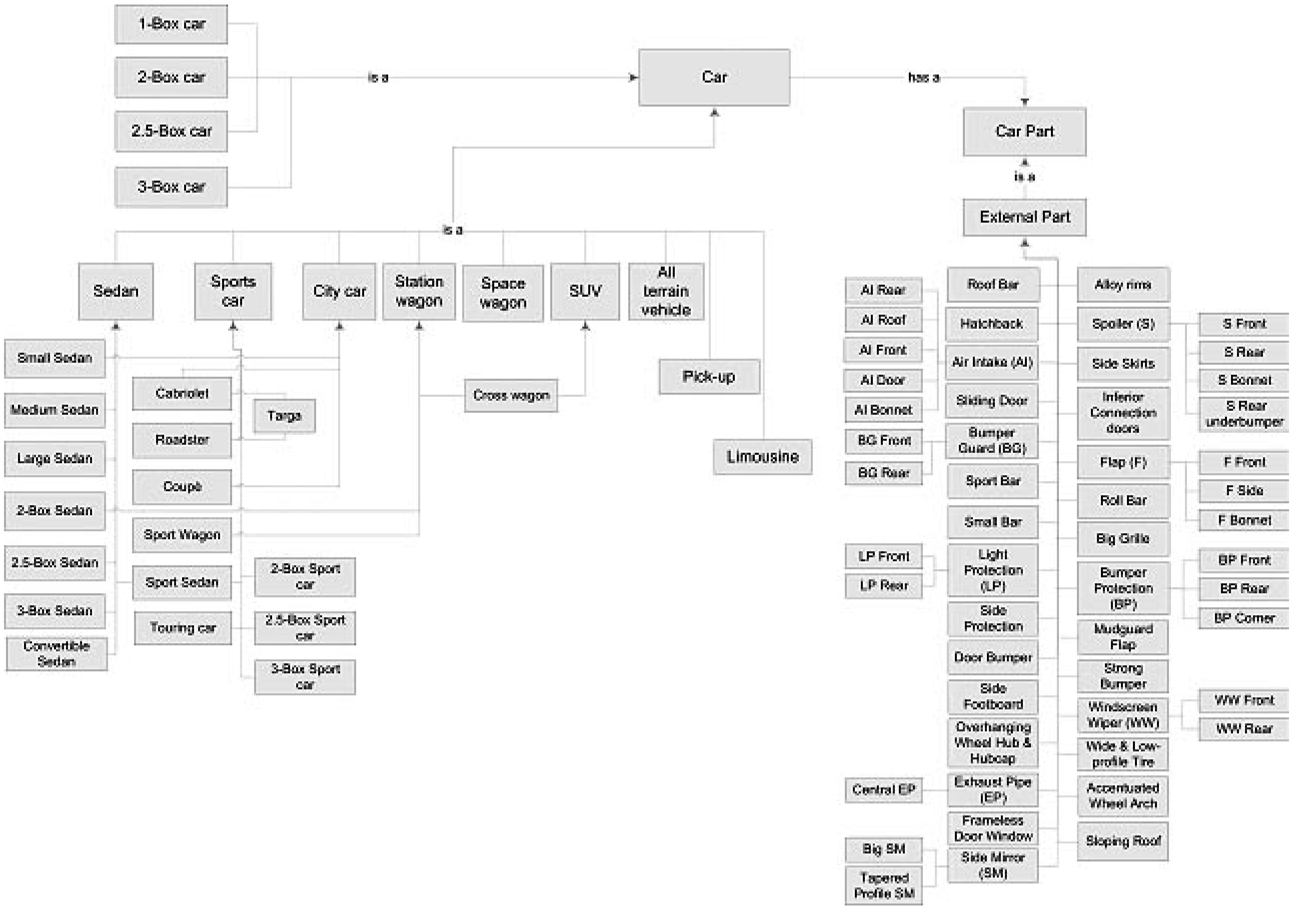

Figure 3. Ontology of car categories and specific parts

Among class properties we considered synonyms in order to qualify each category with alternative terms. For instance *Sedan* is the American English term for *Saloon*, *Saloon car. Sports car* has synonym *Sportster. Station wagon* has synonyms *Estate car*, *Estate wagon*, *Large Estate*, *Brake*, *Hatchback,* while *All terrain vehicle* has synonyms *Cross-country vehicle, Land Rover, Jeep*, and also *Four-by-four, Four-wheel drive* and *All Wheel Drive* (*AWD*). The same applies to the sub classes of each main category (e.g. *Coupe*, *Convertible*).

Other class properties are the parameters for distinguishing between car categories: these are dimensional characteristics, dimensions of packaging (length, width, height), which are calculated according to the standard ISO 612:1978 on definition of dimensions of road vehicles, volumes (i.e. one box, two-box, two-and-half box, three-box car), wheels dimensions, and specific ratios that are used by designers to first characterise the type of car. In particular, the size of the wheels is usually employed by designers as the unit of measure of volumes. *Wheels* are the first entity stylists draw and they build the whole car around them. The length between the wheels (*wheelbase*) can be measured in terms of the number of wheels contained and the type of the car is given by the ratio between the height of the car and the diameter of the wheel: if the ratio is greater than one, the car is an estate one; if it is less, the car becomes sporty. Moreover, if the diameter of the wheel is emphasised by an opening fillet, named *over wheel arch* in the next, the consequent proportions make the car looking compact. The evaluation and comparison of such properties is one of the filters we include to extract the car category from a model not annotated yet.

For further explicitation of domain knowledge, we considered a structure-based approach of cars that takes into account the components of the body and characteristics of parts that are specific to each category (e.g. sloping roof for *Coupe* cars or rear spoiler for *Sports car*).

Some other specific dimensional characteristics are included for easing the identification of some categories, for instance Approach and Departure angles for *All-terrain vehicles* and *S.U.V.*, as shown in Figure 4.

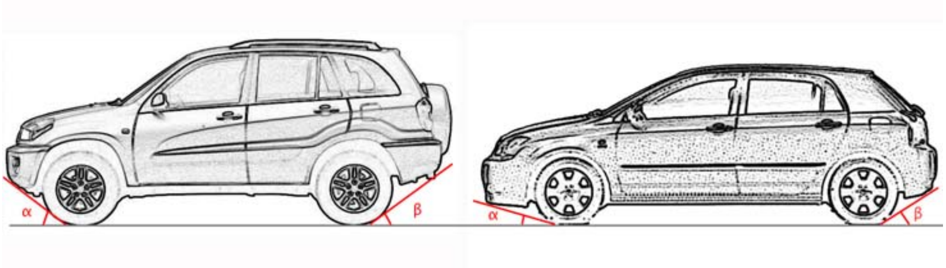

Figure 4. Approach angle (α) and Departure angle (β) are characteristic angles of All-Wheel Drive and SUV (α, β≈30°), other types have α, β<<30° and they are not included in the specifications

Table 2 below summarises characteristic dimensions, volumes, optional external parts and attributes for the first seven categories. The optional external parts are the details that belong to the ***graphics*** of the car.

Category	Term Definition (SRO, 2005)	Volumes and Dimensions	Attributes	Typical Optional Parts
Sedan	Fixed-roof car with at least four doors or any fixed-roof two-door car with at least 33 cubic feet (934 liters) of rear interior volume, according to measurements based on SAE standard J1100	*Volume*: Two-box, Two-and-a-half-box, Three-box car *Characteristic Dimensions*: Limited height (a)	Max 4 side doors Can be Convertible (Class: Convertible Sedan) [four-door convertible]	Alloy rims [one piece instead of wheel rim + wheel cover]
Sports car	Term commonly used to describe a relative small, low slung car with a high performance engine and excellent handling.	*Volume*: Two-box, Two-and-a-half-box, Three-box car, Two-box car (Class: Sport Wagon) *Characteristic Dimensions*: Limited height (<a), Wide vehicle	Small central box (2 sits) (Class: Roadster, Coupe) Max 2 side doors (Class: Coupe) Long wheelbase (Class: Coupe, Roadster, Touring Car) (Class: Targa) intersection of (Class: Cabriolet) and (Class: Roadster) Convertible (Class: Cabriolet) Lack of Rear Windscreen Wiper Double and/or Central exhaust pipe Wide & Low-profile tires Accentuated wheel arches Frameless door window (Class: Coupe) Sloping roof (Class: Coupe) Tapered profile mirrors	Spoiler (Front, Rear, Bonnet, Rear underbumper) Side Skirts Inferior connection doors Flaps (Front, Side, Bonnet) Alloy rims Roll bar Air intakes (Bonnet, Doors) Bumper Corner Protector Grille
City Car	A compact vehicle used for driving within a city rather than on the highway. It is usually only 10 to 12 feet (300 to 360 cm) long.	*Volume*: Two-box, Two-and-a-half-box, Three-box car *Characteristic Dimensions*: small vehicle (narrow and short) compact	Small tyres Can be Convertible (Class: Cabriolet) Can be Coupe (Class: Coupe) Can be Small Sedan (Class: Small Sedan)	Alloy rims
Station Wagon	Originally this was a car with an enclosed wooden body of paneled design with several rows of folding or removable seats behind the driver. It became a different and popular vehicle after 1945. There is usually a tailgate but no separate luggage compartment. Early station wagons and compact station wagons had only two doors while the larger ones had four doors.	Class: Two-Box Sedan *Volume:* Two -Box *Characteristic Dimensions*: Long vehicle	Hatchback High rear (Class: Cross wagon) = union of (Class: Station wagon) and (Class: SUV)	Roof bars
Space Wagon	A vehicle category introduced in the USA in 1983 with the Chrysler Voyager, and in Europe at the end of the 1980s with the	*Volume*: One-Box *Characteristic Dimensions*: Big and Tall vehicle	Long wheelbase Hatchback Windshield slope finishing in line with the front of the car	Roof bars Sliding doors

	Renault Espace; a multi-purpose vehicle for everyday and recreational use that combines the handling and luxury of a sedan with the space and headroom of a van; usually with three rows of seats for at least six people and with a sliding door on the side.			
S.U.V.	A vehicle built on a truck chassis but is configured much like a station wagon.	*Volume*: Two-box car *Characteristic Dimensions*: Tall vehicle, high from ground (b)	Approach angle (α≤30°) Departure angle (β≤30°) Accentuated wheel arches Big tyres but more Low Profile than 4x4 Big Side Mirrors General shape close to (Class: Station wagon)	Bumper guards (Front, Rear) Roof bars Alloy rims
All terrain vehicle	A vehicle used in rough surface conditions	*Volume*: Two-box car *Characteristic Dimensions*: Tall vehicle, high from ground (>b)	Approach angle (≥ α) Departure angle (≥β) Accentuated wheel arches Side molding Tall tyres Big Side Mirrors	Alloy rims Overhanging wheel hub and hubcap Strong Bumper Bumper protections (Front, Rear) Lights protections (Front, Rear) Sport Bar Small Bar Front grill Air intakes (Roof, Front, Rear, Bonnet) Side protection Spoiler (Front, Rear) Side footboards Side skirts Mudguard flap Door bumper Roof bars

Table 2. Summary table of concepts and properties of car categories

4.2 Treatment

Even if the final result of the design process is the complete and detailed definition of the surfaces constituting the final shape of the product, the character evaluation and modification is performed by concentrating on specific curves of the object, e.g. sections and reflection lines, which are normally judged in a planar view (paper or CAD screen). Therefore, with the term *treatment* we refer mainly to those curves contributing to express the global character of a car. Such curves can be both real and virtual curves: in fact, they can be part of the contour but also reflection lines, or more generally lines related to the smoothness of the surface. In order to formalise some typical qualities of a car, a taxonomy of the key curves candidate to elicit some emotions and their properties is proposed here. However, single curves are not usually enough to express a character and it is more common that some specific properties of specific curves together with special relationships among such curves define the predominant character of a car. The (aesthetic) relationship between curves can be of two types:

- Geometric relations between adjacent curves: in this case, the aesthetic effect is given by the type of connection between the two curves (e.g. kind of blending, kind of radius)
- Geometric relations between not adjacent curves: in this case, the aesthetic effect is given by the mutual position between the two (e.g. parallelism, angle of incidence, symmetry).

Only some relations have aesthetic results, then they are made explicit for the different characters.

In this section, first a taxonomy of the *aesthetic key lines* (*akls*) will be described, then the aesthetic properties and relationships will follow.

4.2.1 Aesthetic Key Line taxonomy

To group simpler the *aesthetic key lines*, we consider sketches showing the 2D views used in practice. For clarity, we subdivide curves according to two main projection views: the side first and the front/back views are the most important to show the character. In Figure 5, a taxonomy is shown, distinguishing between profile curves and other character lines.

In the *profile* category, the different portions of the contour of the car sketched have been named and put in an adjacency sequence. Among the *aesthetic key lines*, the *roof line*, the *windshield line* and the *wheelbase line* in the side view are the most significant. The *roof line* and the *wheelbase line* are the first curves sketched by the car designer, just after the wheels. In fact, they both identify the packaging and start to suggest the style. On the other hand, *the windshield line* with its slope and length contributes to the definition of the aesthetic and aerodynamic quality of the vehicle shape, through its influence on the drag coefficient, which is used on the calculation of the aerodynamic drag. In the *Character line* category are included all the real and virtual curves affecting the character of a car. Among these, the *waist line* and the *accent line* have particular relevance for the car style; the *waist line* is a curve defining the change of the material between the auto body and the glass of the windows; it is often coupled with the *accent line*, a virtual line which expresses the reflection of the light on the surface. The *accent line* is related to the curvature of the surface in the surroundings of the *waist line*; it can be also represented by a sharp line with a strong aesthetic effect. The *over the wheel arch* has usually the effect to emphasise the wheel rim, giving more compactness or stability to a car. In all the views, some peculiar *brand lines* can elicit the family feeling in order to make a car company philosophy recognisable directly from the shape of the vehicle. In some cases, as for Alfa Romeo, the character lines on the hood converging to the logo are definitely brand lines, together with the shape of the triangular front grille. The shape of the lights has also a visible influence on the character of the car. In Figure 6, the different *aesthetic key lines* are shown.

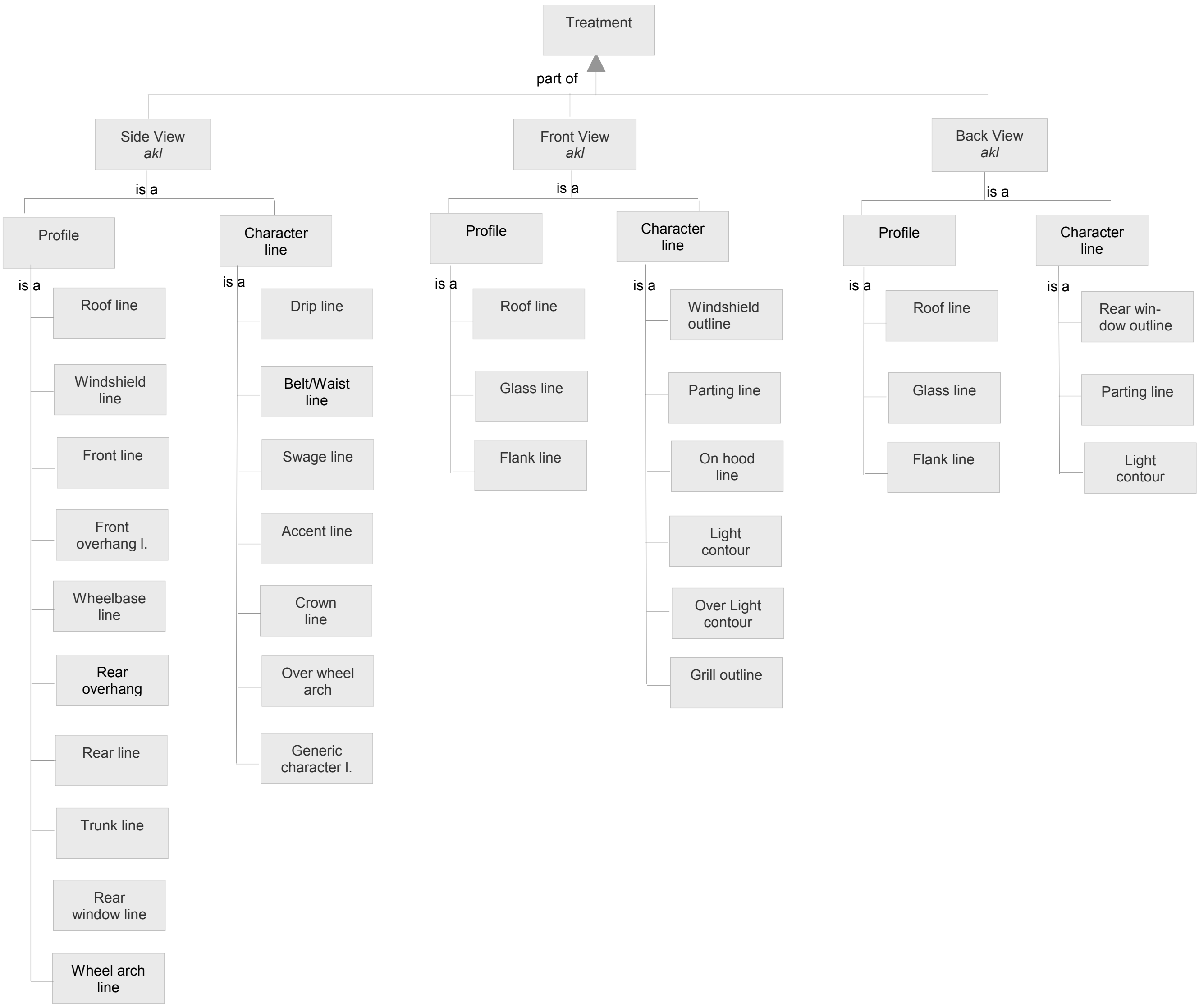

Figure 5. Treatment ontology

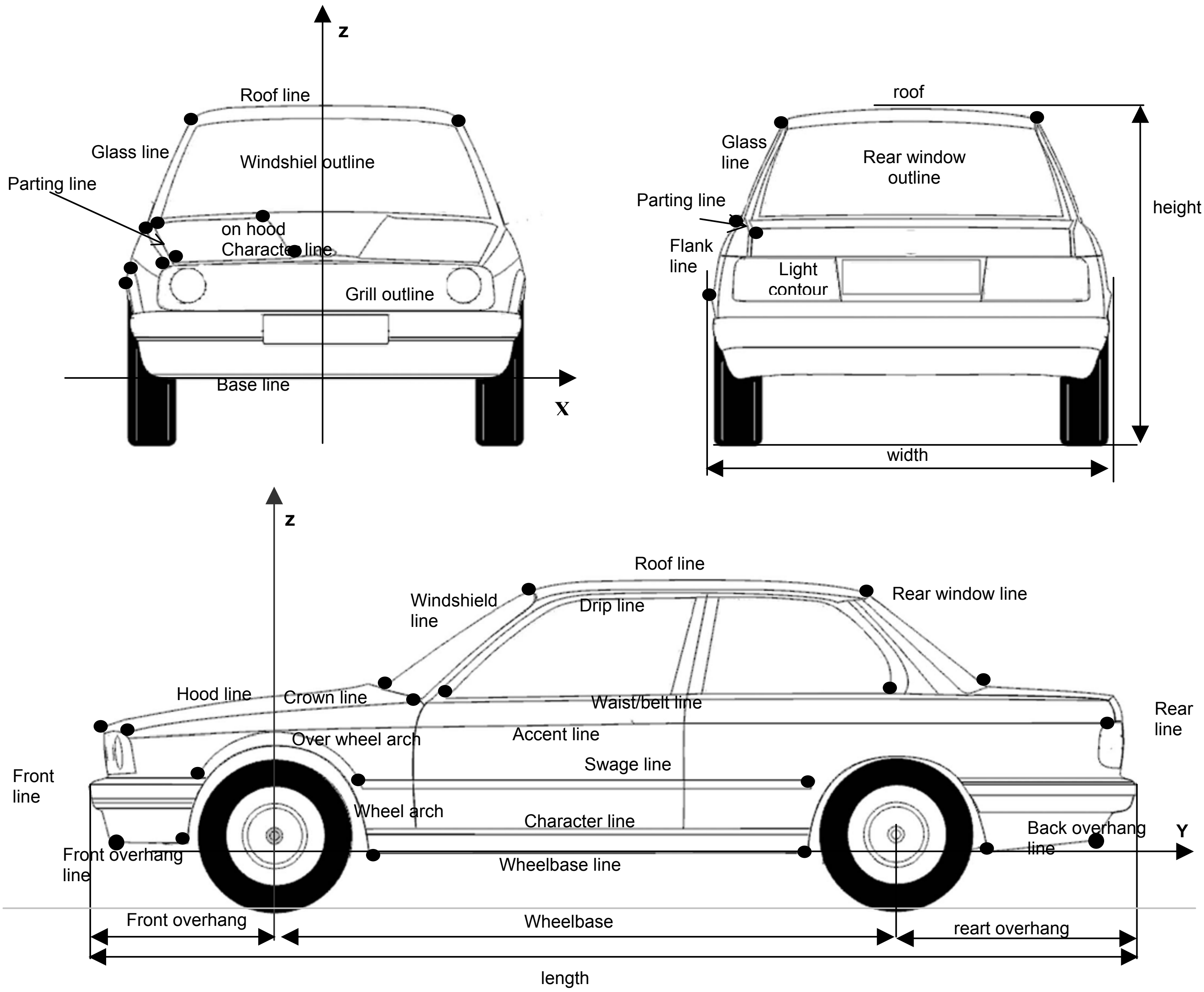

Figure 6. *Aesthetic key lines* of the treatment

4.2.2 Aesthetic properties

Once defined a taxonomy of the treatment curves, the A*esthetic Properties* (*APs*) of such lines have to be defined. They are certainly related to the geometry, but in a complex way, and act on the aesthetics of the shape.

The FIORES-II consortium has mainly concentrated on those properties corresponding to the terms used by stylists for expressing desired shape modification: in particular, the concepts of *acceleration, softness/sharpness, tension, convexity/concavity, flatness, crown* have been defined together with their measures (Giannini et al., 2004). They will be useful in section 4.3 for the formalisation of the dominant character, thus it is convenient to briefly summarise their definitions here. Considering the whole curve, the *acceleration* is related to how much the variation of the tangent to the curve is balanced along it; so, even if curvature maxima are present but distributed along the curve, this result not accelerated. The term

softness/sharpness is used to describe the properties of transitions between curves or surfaces. In styling, the term *radius* is generally used to indicate a more rounded transition (a blending) between two curves or surfaces; in general, a small radius can be called sharp, and a big radius can be called soft. When designers make a curve more *convex* (or *concave*, in the opposite direction), they are moving towards the enclosing semi-circle; thus, the ideal convex curve is the semicircle, or an arc of circle, if the continuity constraints at the endpoints are compatible with, otherwise it is the curve presenting the lowest variation in curvature that satisfies the given continuity constraints. According to the user's axiomatic feeling "Straight lines have either no tension or an infinite one", *tension* has been defined as the "internal energy" of a curve subject to continuity constraints at its boundaries required to change its shape according to its boundary continuity constraints, provided it is not a straight line; this can be geometrically translated into an evolution of curvature along the curve, which means that increasing the tension of the curve leads to a larger part of small curvature. *Flatness* is simply related to how much the curve tends to a straight line. Curves including some inflection points are called referred as *wet curves* or *S-shaped*. *Putting on crown* means lifting or raising a certain part of the curve in a given direction or surface, without changing the end points, and eliminating the inflection points –if any- while creating a convex part.
The *APs* have been associated with a measure, which is not treated in this paper. For simplicity, we will use the notation:

$$akl.isX = akl.hasPropertyX(threshold\ value)$$

Shortly, then,
$\forall akl\ AP(akl) \in \{isAccelerated,\ isSoft,\ isSharp,\ isTensed,\ isConvex,\ isConcave,\ isFlat,\ isWet,\ isCrown\}$.
Regarding the relationships between two curves, valid in a certain view, we define the following:

$$\forall i,j\ akl_i.hasRelationWith(akl_j),$$

where

$$hasRelationWith \in \{hasConjunctionWith,\ isParallelTo,\ isIncidentTo(\alpha),\ isSymmetricWrt,\ isTangentTo\}$$

and

- *hasConjunctionWith* refers to the kind of blending/radius between two aesthetic curves;
- *isParallelTo and is TangentTo* specify the parallelism and the tangency, respectively, between two curves;
- *isIncidentTo*(α) indicates that two curves form an angle of α degrees;
- *isSymmetricWrt* claims a symmetry of a curve with respect to a straight line.

4.3 Aesthetic Character

In the following subsections, only the main characterisations of the basic aesthetic characters will be formally expressed through a logic symbolism.

4.3.1 Sportiveness

In this case, it should be distinguished between a *sports car* and a sportive car. A *sports car* belongs to a special category of car; anyhow, all sports cars are sportive. Then, for sports car, it is the volume to be more involved, as explained at the beginning of the section, whereas a car is sportive mainly because of its treatment and graphics. In particular, an alternation of different materials and colours is the common graphics, plus the possible presence of typical optional parts such as spoilers.
Regarding the ***treatment***, the *accent line*, the *over wheel arches*, the *roof line*, the *rear overhang* have a fundamental importance: in general, they are evident and possibly sharp; in particular, the *roof line* is generally tensed, while the *accent line* can be sharp. The latter is often tensed as well, but sometimes a wet curve is chosen instead:, the *roof line* will

counterbalance this softness effect with a very tensed behaviour. Then, it is generally true the formula

$$\forall akl \in treatment,\ akl.isTensed \wedge (\exists akl\ akl.isSharp);$$
$$accent\ line.isWet \rightarrow roof\ line.isTensed.$$

The *over wheel arch* is often evident: this has an impact both on the volume and the treatment. In fact, a prominent *over wheel arch* enlarges the width of the wheel giving a feeling of compactness. The prominence effect can be created either putting crown in the area around the wheel arch or inserting a sharp *over wheel arch*. It often happens that the *accent line* vanishes into the *over wheel arch*:

$$over\ wheel\ arch.isSharp \vee over\ wheel\ arch.isCrown;$$
$$accent\ line.isTangentTo(over\ wheel\ arch).$$

Another peculiarity is that the rear overhang is short to give the idea of dynamism:

$$length(rear\ overhang)<\delta.$$

Clearly, the idea of sportiveness is associated to the idea of dynamism and possibly to the aggressiveness, thus the three characters will probably coexist in a car. An example of sportive character related to a choice of a car company is provided by Alfa Romeo, which emphasises the sportiveness in all its models.

4.3.2. Dynamism

The concept of dynamism is strictly related to the car aerodynamics. In practice, such a character is obtained by giving *directionality* to a car. Ideally, this translates into flat lines in the profile view, i.e. straight *accent line*, *roof line and waist line*, which converge to a point in the movement direction. Together with directionality, the dynamic effect is provided by the sloping angle between the profile lines with the *wheelbase line*. Considering the linear approximation of the *akls* involved, the wider the angle with the *wheelbase line*, the more dynamic the effect. In principle, the angle may be widened until the engineering constraints are contradicted. More formally,

$$\forall akl_i \in \{roof\ line,\ accent\ line,\ waist\ line,\ crown\ line,\ front\ line\}$$
$$windshield.isFlat \wedge akl_i.isFlat \wedge (akl_i.isIncidentTo(wheelbase\ line, \alpha_i) \wedge \alpha_i \in (\beta,\gamma)) \quad (1)$$

where β,γ are threshold values.

Another complementary way to gain dynamism is related to the inclination of the *drip line* and the *windshield line*: they follow the same directionality as the *akls* considered above, moreover the *windshield line* is more sloped.: the *roof line* is often flattened in the back of the car and made crowner at the windshield, giving a round effect at the joint:

$$(\forall i\ akl_i.isIncidentTo(wheelbase\ line, \alpha_i) \wedge windshield.isIncidentTo(wheelbase\ line, \alpha') \wedge$$
$$\wedge (\forall i\ \alpha'>\alpha_i);$$
$$windshield.hasConjunctionWith(roof\ line)=soft.$$

Dynamism is a character depending on the category of the car. Thus, while a *sports car* or a *sedan* can follow the general principles just mentioned, this cannot be applied straight to a *city car*, which is shorter (packaging constraints). For a *city car*, more than by directionality and flat lines, dynamism is given by tensed lines, therefore, (1) becomes:

$$\forall akl_i \in \{roof\ line,\ accent\ line,\ waist\ line,\ crown\ line\}$$
$$windshield.isTensed \wedge (\forall i,j\ akl_i.isTensed \wedge akl_i.isParallelTo(akl_j)) \wedge$$
$$\wedge (akl_i.isIncidentTo(wheelbase\ line, \alpha) \wedge \alpha \in (\beta,\gamma)),$$

where the condition on the angle is less strong and could fail.

4.3.3. Aggressiveness

Aggressiveness is often associated with the idea of speed, then with dynamism and sportiveness. As a consequence, it will be hardly attributed to a *city car* or a *family car*, which have stability and security as main feelings to elicit.

In general, aggressiveness is related to the front part of the car. Therefore, the *akls* influencing most the character are specially the *hood*, the *accent* and the *roof lines*. In the profile view, the curves belonging to the hood will be accelerated in the front part, in the front view the *light contours*, the *grille outline* and the *on hood line* have a big role: stretched out rather than round light contours give an aggressive feeling. Side character lines, *roof, hood* and *accent lines* are normally very accelerated curves following the profile behaviour.

$$(\forall akl \in \{akl_i \mid akl_i \in \textit{front view curve} \vee (akl_i \mid akl_i \in \textit{side view curve} \wedge akl_i \in \textit{front-part})\}\ akl.isAccelerated) \wedge \textit{light contour.isSharp},$$

where

front-part={roof line, windshield line, front line, front overhang, drip line, waist line, swage line, accent line, crown line}.

4.3.4. Elegance

Elegance is maybe more subjective than the character analysed before. Some car categories are better candidates for the evaluation of the elegance because of their target customers. This applies to *sedans, station wagon*, possibly *sports cars*, but less commonly to *city cars* since elegance has to convey the luxury feeling.

Elegance can be obtained with treatment and graphics. The general principle is to create harmony and this can be translated into smooth surfaces and transitions, opportune material and colour choices and colours. Normally, elegance is the opposite of sportiveness, therefore it is given by no changes in materials and with less additional details. As a consequence, there are no too many character lines, the *akls* are generally tensed, not sharp and not wet. Sharp character lines are not elegant, thus sportive cars, often including sharpness, are in general not elegant:

$$\forall akl\ akl.isTensed \vee \neg akl.isSharp \vee \neg akl.isWet;$$

$$akl_i.hasConjunctionWith(akl_j)=soft\ \forall i,j.$$

4.3.5. Friendliness

Friendliness is often referred to *city cars* and it is generally disjoint from the aesthetic characters described so far. In terms of proportions, friendliness can be easily associated to “square” packages.

Many *akls* will be soft (i.e. not tensed), some even round; in fact, using precise circles can give the feeling of fancifulness/fantasy. Among the *akls*, a friendly character can be assigned to the *roof line* together with the *over wheel arch*, on the *accent line* or on the *drip line*. The *over wheel arch* is usually evident and quite round. Also the light contours are often round, or at least soft.

$$(\forall akl \in \{\textit{roof line, over wheel arch, accent line, drip line, light contour}\}\ \neg akl.isTensed) \wedge$$

$$\wedge\ \textit{over wheel arch.isConvex} \wedge (\textit{over wheel arch.isSharp} \vee \textit{over wheel arch.isCrown}) \wedge$$

$$\wedge\ \textit{light contour.isConvex}.$$

4.3.6. Stability

Stability is naturally associated to all categories of cars, even if for some typology of cars is more emphasised, e.g. for *family cars*. In the profile view, it is the *roof line* to have the highest weight: if the *roof line* is symmetric with respect to the axis of the wheelbase line, then a car can be considered stable. On the other hand, stability is given by tensed *akls,* the *roof line*, the *accent line* and the *waist line* in particular.

$$(\forall akl \in \{\textit{roof line, accent line, waist line}\}\ akl.isTensed) \wedge$$

$$\wedge\ \textit{roof line.isSymmetricWrt}(axis(\textit{wheelbase line})).$$

However, it is the symmetry of the elements with respect to the axis of the wheelbase which amplifies the feeling of stability:

$$\forall akl \in \textit{profile view curve}\ akl.is\ SymmetricWrt(axis(\textit{wheelbase line})).$$

In the front or back view, the position of the wheel with respect to the flank gives an indication of stability: the closer the wheels are to the flank, the stabler the car, and viceversa.

5. Conclusions

The development of a new car normally starts with the evaluation of already existing models with the objective of taking inspiration either for creating similar cars or for achieving a completely innovative solution. To fully take advantage of the already available car models and data, they should be adequately annotated according their category and aesthetic character. Considering the economical un-sustainability of letting CAD experts annotate existing models, it is evident how tools able to (semi-) automatically perform such a task would provide a great benefit. Such tools can only be realised if a formalisation of what constitutes a style and of how such elements can be translated and derived from the shape geometric description matures.

Taking advantage of the experience gained in our previous European projects working with car stylists, in this paper we focused on such a formalisation identifying the key elements and their mutual relationships, which provide specific car categorisations and aesthetics. Regarding the GR and IP tools needed for the shape analysis of the resources, the basic methods are currently available, whereas what is still missing is their adaptation and usage according to this specific context knowledge. However, some rules can be devised in the automotive field, being a car a structured product with well-established components and shape characteristics. Our future activity will be the completion of the *Car Aesthetics Ontology* and the implementation of the annotation system.

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