Doctoral Thesis Proposal

Languages of Styles: Ontology, Representation and Reasoning about Aesthetics in a Computational Framework

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1 Introduction

Aesthetic knowledge is ubiquitous in the common-sense description and evaluation of both material things and intellectual objects, and many everyday decisions are based on the judgement of aesthetic properties of the admissible choices.

A recent qualitative sociological analysis [108], shows the increasing perceived importance and pervasiveness of aesthetic values:

> Having spent a century or more focused primarily on other goal-solving manufacturing problems, lowering costs, making goods and services widely available [...] we are increasingly engaged in making our world special.
>
> We are demanding and creating an enticing, stimulating, diverse, and beautiful world. We want our vacuum cleaners and mobile phones to sparkle, our bathroom faucets and desk accessories to express our personalities. [...] We demand trees in our parking lots, peaked roofs and decorative facades on our supermarkets, auto dealerships as swoopy and stylish as the cars they sell.

Nowadays, material and immaterial production and distribution have been mastered so well, that function and value of industrial artifacts become givens, thus making style and look-and-feel issues the main battlefield of marginal competition. Design, therefore, has come to have real and substantive economic value.

As a consequence of this trend, there is a growing interest toward the nascent field of Computer Aided Aesthetic Design (CAAD), that aims at developing software tools that:

- handle aesthetic knowledge as a first-class citizen, enabling its representation, storage, querying and sharing;
- link aesthetic knowledge to non-aesthetic knowledge, supporting inter-operability between semantically-augmented software tools and more traditional ones, and enabling communication between aesthetic and engineering designers.

Current state-of-the-art approaches to CAAD are mainly focused on the development of quantitative similarity models for specific aesthetic features [50, 107], whereas the Design Studies community expresses a strong need [111] for a general, symbolic approach to representation and processing of aesthetical information.

Within this broad context, I am focusing my investigation toward the following two open themes:

1. the definition of a formal language for the representation of the aesthetic proprieties of human artifacts (first as a formal ontology, and then as a structured metadata language for the "semantic" mark-up)
2. the study of the concept of *aesthetic judgement*, seen as an arbitrary, purely qualitative decision following from the evaluation of a decision problem that involves multiple strictly incompatible and irreducible criteria. Specifically, the aim is toward the explicit representation of the *justification* of the judgement.

This doctoral thesis proposal is organized as follows: Section 2 outlines the goals and the methodology of the proposed research activity, Section 3 suggests a number of technological applications of the expected results, and Section 4 briefly surveys the history and the state of the art of the related research efforts.

2 Goals and Methodology

The investigation shall be carried out on both theoretical and applicative sides. The theoretical investigations will be methodologically consistent with the current trends of formal artificial intelligence research. In particular:

- research on Formal Ontology in Information Systems, [55, 56, 47, 59, 98];
- research on Knowledge Representation Languages, [8, 120, 46, 114, 7];
- research on Semantic Web, [74, 73, 34, 33, 35].

The major focus of these studies is the interplay and the tradeoffs between the following aspects:

- complexity of the algorithms for solving constraints satisfaction problems and performing other reasoning tasks;
- completeness and soundness of the corresponding logical model;
- adequacy and practical usefulness for the intended end-users of the system.

I will address the same concerns in the specific context.

On the applicative side, implementation issues will be addressed with the study of a prototype of a Knowledge System that will exploit the expected theoretical results. For this part of the investigation I will employ up-to-date methodologies and tools of both Software and Knowledge Engineering.

The remainder of this Section is organized as follows. In Subsection 2.1 I give a first overview of the applicative domain of human artifacts from the point of view of the representation of aesthetic properties, and I motivate the choice of *styles* as the main ordering principle.

In order to define a formal language, it is necessary to develop an *ontological layer*, that provides a catalog of the types of entities that I am interested to model in the domain of artifacts, from the perspective of an agent who uses the language itself for the purpose of talking about aesthetic properties, and a *logical layer* that provides the formal structure used to encode the knowledge, and the rules of inference used to reason about the represented entities. Subsection 2.2 outlines ontological issues, whereas Subsection 2.3 outlines logical issues.

Subsection 2.4 deals with the issues concerning the implementation of the language in applicative software tools and systems. Subsection 2.5 gives same perspective on modelling aesthetic similarity and explicitly representing justifications of aesthetic judgements.

2.1 Artifacts and Styles

Artifacts are entities built by human craft. Their distinctive characteristic is that they are the product of human conception and agency: if an artifact exists, a plan has been devised and carried along in order to shape it.

The taxonomy of artifacts I introduce here has been adapted from [22]. It has been developed using the Guarino-Welty methodology and will be used as the basic structure of the ontology.

2.1.1 The Guarino-Welty methodology

The Guarino-Welty methodology [133, 59] provides a classification of unary properties (corresponding to taxonomical entities) by means of some meta-properties (based on the notions of *rigidity*, *identity*, *unity* and *dependence*), and then uses this classification to discipline the use of subsumption relations.

The meta-properties taken into consideration are the following ones. The domain of quantification for instances is what exists in any possible worlds.

- *Rigidity.* A *rigid* property (**+R**) is a necessary property for all its instances; a *non-rigid* property (**-R**) is not a necessary property for all its instances; an *anti-rigid* property (∼**R**) is an optional property for all its instances. ∼**R** implies **-R**.
- *Identity.* We take into consideration *identity conditions* (IC) that can be both necessary and sufficient, only necessary or only sufficient. A property may *supply* an IC (**+O**), only *carry* and IC (**+I**) (i.e., inherit it from a subsuming property), or *not carry* an IC (**-I**). **+O** implies **+I**, **-I** implies **-O**.

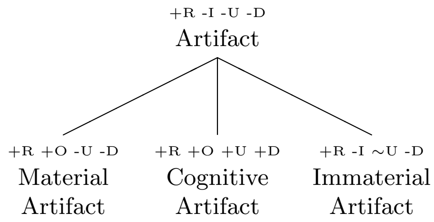

Figure 1. Taxonomy of artifacts

- *Unity.* An *unity condition* (UC) is an equivalence relation ω such that all its instances are *intrinsic wholes* under ω. A property may *carry* and UC (**+U**), *not carry* an UC (**-U**) or have *anti-unity* (∼**U**) if every instance of the property is not an intrinsic whole. ∼**U** implies **-U**.
- *Dependence.* A property Ψ is *(externally) dependent* (**+D**) from a property Φ if, for all its instances x, necessarily some instance of Φ must exist, which is not a part[1] nor a constituent of x. Otherwise the property is not dependent (**-D**).

If Ψ is a propriety, the notation $\Psi^{\mathbf{X}}$ is used to indicate that the meta-property **X** holds for Ψ.

The consistency constraints imposed on the taxonomy are the following ones:

- $\Phi^{\sim\mathbf{R}}$ can not subsume $\Psi^{+\mathbf{R}}$;
- $\Phi^{+\mathbf{I}}$ can not subsume $\Psi^{-\mathbf{I}}$;
- Properties with incompatible ICs are disjoint;
- $\Phi^{+\mathbf{U}}$ can not subsume $\Psi^{-\mathbf{U}}$;
- $\Phi^{\sim\mathbf{U}}$ can not subsume $\Psi^{+\mathbf{U}}$;
- Properties with incompatible UCs are disjoint;
- $\Phi^{+\mathbf{D}}$ can not subsume $\Psi^{-\mathbf{D}}$;
- Every domain element must instantiate some property carrying an IC;
- If two entities are the same, they must be instances of a property carrying a condition for their identity.

2.1.2 A taxonomy of artifacts

The domain of artifacts is partitioned by three mutually exclusive properties (see Figure 1): material artifacts, cognitive artifacts and immaterial artifacts.

- *Material Artifacts* are artifacts that are also physical objects, with spatial and temporal qualities. Typical examples are furniture, cars, houses, clothing and so on. Two material artifacts are identical if they share the same spatial and temporal location.
- *Immaterial Artifacts* are artifacts that are immaterial entities, but still have spatial and temporal qualities. Examples are artistic performances, conferences, lectures, athletic competitions, religious practices, and so on.

A fundamental difference between material and immaterial artifacts is that the former are *endurants*, whereas the latter are *perdurants*. The following definition is taken from [98]:

[1] A suitable mereological theory is needed to formalize this definition, such as the one described in 2.2.4

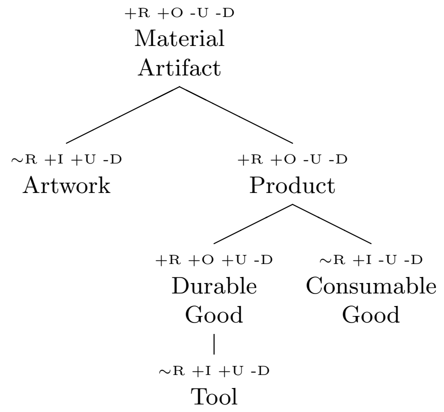

Figure 2. Taxonomy of material artifacts

Classically, the difference between enduring and perduring entities is related to their behavior in time. Endurants are *wholly* present (i.e., all their proper parts are present) at any time they are present. Perdurants, on the other hand, just extends in time by accumulating different temporal parts, so that, at any time they are present, they are only *partially* present, in the sense that some of their proper temporal parts (e.g., their previous of future phases) may not be present.

The notion of cognitive artifact is still debated, but nevertheless it is clear that the property of cognitive artifacts is intrinsically different and disjoint from the other two. I present here a tentative definition.

- *Cognitive Artifacts* are the result of a process of *discovery/invention* that originates a *material relation* between an abstract entity (i.e., an entity without spatial and temporal qualities, and that exists anywhere in time) that we call *the content*, and a non-abstract entity, that we call *the support*. The material relation is not an abstract entity, since it has a commencement in time.
  Examples of cognitive artifacts are literary and musical works, mathematical theorems, and so on. Two cognitive artifacts are identical if they are the result of the same process of discovery/invention.

Using the Guarino-Welty classification of properties [59], Material Artifact and Cognitive Artifact are *types* since they are rigid proprieties that supply their own identity condition, whereas Immaterial Artifact are a *category* since they are rigid too, but but neither supply nor inherit an identity condition.

The upper level of the taxonomy of material artifacts includes the following properties (see Figure 2.1.2):

- *Artworks* are material artifacts that constitute works in the graphical or plastic arts.
- *Products* are material artifacts that are created by means of a manufacture process, either industrial or by craftsmanship.
- *Consumable goods* are products that are expected to be depleted or worn out by use.
- *Durable Goods* are products not significantly depleted or consumed by use.
- *Tools* are durable goods with a prominent functional purpose.

This taxonomical analysis of material artifacts is meaningful, since one of the most relevant themes of Design Studies is the investigation of the relationship between *form* and *function*, that is, between aesthetic and ergonomic/functional qualities of artifacts. Obviously, aesthetic traits are prominent and substantially unconstrained in the class of artworks, whereas they are usually subordinate to functional traits in the class of tools. Products are a sort of gray area, where the interplay between form and function is perceived as a very important issue by both users and marketing analysts. Also, the collaboration between engineers and style designers is often challenging.

I will focus my investigation toward the study of aesthetic properties of material and cognitive artifacts, thus disregarding immaterial artifacts.

It is worth noting that material and cognitive artifacts, although ontologically very different, are deeply correlated, since it is often the case that a material artifact has the role of support of a cognitive artifact.

2.1.3 Aesthetic properties and Styles

The other fundamental notion of the ontological level is *style*.

'Style' is the current commonly used term for a concept that has been known and used in Art History and Art Critique through the ages: *canon* for plastic and graphical arts, *genera* in architecture (as in the derivative French word *genre*, which is used in broader contexts), *maniera*, as used by Giorgio Vasari [132] to describe individual styles of artists, nations and periods (as in the derivative English word *manner*).

A style should identify the nature of an organic but simultaneously disseminated coherence. This is a difficult concept to be captured by commonly used top-level ontologies. An account of the foundational issues can be found in [28, 96], and in [83].

Throughout the last three centuries, a wide number of philosophical theories have been devised to explain the origin and evolutions of styles (for a summary, see [88], chapter 1). The common assumption behind these theories is that aesthetic choices are ultimately driven by forces that lie outside the conscious free will of the artists and the craftsmen.

I propose a first classification of these forces in two main categories: the aesthetic properties that can be ascribed to specific biological features of the human cognitive system on one side (let's call them *ground*), and the indirect, culturally and socially constructed aesthetic properties on the other side (let's call them *constructed*).

A (tentative and non-exhaustive) list of ground aesthetic properties includes:

- **Perceptual qualities**. Colors, sizes, shapes, sounds, smells, tastes, convey important aesthetic information. For each one of these qualities, on one side we have a number of results from cognitive, psychological and sociological studies that give an account on how they influence the aesthetical judgement of human beings, and on the other side we have (often quantitative) formalizations of the quality spaces (the sets of the possible quality values), in terms of objectively measurable entities. Methodologically, the language of styles should aim to integrate the two sides, with the goal of providing a formal mean to express aesthetical knowledge on perceptual qualities.

As an example, let us consider **Color**. There are many works in the Color Research field that study, by means of psychological experiments and statistical analysis, the impact of color and color patterns on people's feelings; see [89, 42] for an account of some recent results, and [78, 2, 52] for the foundational works in Color Theory. Although color is an important element in cultural symbologies, it has been proved that the majority of the moods conveyed by colors is culturally independent.

Conversely, there is a wide number of different models for formally representing colors (as they are ideally perceived by a human being) with tuples of numbers [44].

- **Proportions between measures, and Golden Ratio**. It is widely recognized that different proportions between measurable properties of both visual or auditive entities convey different and specific aesthetical values [43]. The most significant example, the Golden Ratio (*proportio divina* or *sectio aurea*) is the number:

$$\phi = \frac{1+\sqrt{5}}{2} \approx 1.618$$

It it the only real number greater than 1, that, for positive a and b, has the notable property that:

$$\phi = \frac{a}{b} = \frac{a+b}{a}$$

Literally everywhere in the human environment and history there are evidences for a cognitive preference for entities that have measurable qualities with ϕ proportions. For a discussion of the mathematical properties of the golden ratio, see [119]; for an account of its use (and the use of other proportions) in Art and Design, and for references to psychological research on this subject, see [43].

The formalization of the notion of proportion between measures, require an account of the notions of *measure* and *real numbers*. Measure is a predicate M defined on properties, that must satisfy the following necessary condition:

$$M(p) \rightarrow p(x, \alpha) \rightarrow Real(\alpha)$$

A specific proportion between measures, such as the Golden Ratio, can be defined as

$$GR(p_1, p_2) \equiv M(p_1) \wedge M(p_2) \wedge p_1(x, \alpha) \wedge p_2(x, \beta) \wedge \frac{\alpha}{\beta} = \phi$$

Even if this definition can be squeezed into first order logic, it requires a higher order setting to be effectively useful (e.g. to existentially quantify proportions, or to combine them with relevancy theory). This is an issue that needs to be addressed.

- **Rhythm**. Rhythm is a fundamental feature of nearly all artistic disciplines, from music to poetry to architecture [11, 3]. Repetition of a modular unit, variations in repetition, gradation, anomaly in repetition are basic patterns in Graphical and Plastic Design [135].
- **Symmetry**. Symmetry is another characteristic universally judged as pleasurable [5]. In nature, it is an evident distinctive feature of healthy living beings, and thus it is supposed to be an important criterium for the choice of mates [11].

Gestalt Theory was devised in the early 20th century by Kurt Koffka, Max Wertheimer, and Wolfgang Köhler, as a study of pattern perception. They observed that, although environments could theoretically be interpreted as being composed of arbitrary entities, people consistently perceived them as a specific arrangement of specific entities. They isolated a set of innate mental *principles of perception* which accurately predict the way objects are perceived: *proximity*, *similarity*, *constant direction*, *closure*, *habit*. When different applications of the principles lead to different possible perceptions of an environment, the structurally simplest one is usually chosen. More recently, Emanuel Leeuwenberg introduced *Structural information theory* (SIT), a formal calculus that embeds some of the original ideas of Gestalt Theory. In 1998 Mehdi Dastani introduced a formal algebra for SIT [39], that allows the use of more general and domain-specific operators.

SIT should provide a suitable framework for the formalization of *Symmetry* and *Rhythm* as aesthetical properties, since it provides specific algebraic operators for symmetry and repetition.

- **Balance**. We are biased by the fact that we live in an environment where the gravitational field points toward the bottom of our visual field, and by the fact that we read from left to right[2]. As a consequence [91], we interpret graphical representations traversing them from the top left to the bottom right, and many pictorial representations (such as paintings, or comics) exploit this bias to induce a temporal "narrative" ordering in the way we interpret the elements in the picture [100]. Furthermore, even when we look at abstract graphics (such as an abstract painting, or a technical diagram) we tend to judge them as more natural and more pleasurable if they put more "weight" on the lower part of the visual field (by putting there darker colors, or more complex content). The spatial qualities of many prominent artworks are slightly asymmetric in order to accommodate these cognitive biases [5].

Constructed aesthetic properties, conversely, account for the individually, culturally and socially constructed connotations that are inevitably produced when the artifact is designed, produced and then fruited. I maintain that *Semiotics* [29] provides both a theoretical framework and a rich set of tools for the analysis of such entities.

Ultimately, all aesthetic characteristics relate to the perceptual and cognitive ground; the goal of the semiotic analysis is to track the flow of their meanings through signs,

[2] This is a constructed feature, since there are some written notations that are read from right to left, or from top to bottom, but its effects are so 'low level' that they are better described as cognitive rather than cultural biases.

codes, rhetorical tropes and chains of connotations.

Design philosopher Terry W. Knight [88] maintains that:

> The concept of style is used basically as an ordering principle. It allows the vast domain of individual artifacts and phenomena to be structured. [...]
>
> Within the arts, the concept of style is typically used to describe consistencies among works that are products of an individual, school, culture, time period, or geographic region. Once stylistic categories are established, these are turned to predictive purposes, to identify works of unknown origins; [...]
>
> The grouping of works of art into styles is a prerequisite for studying stylistic transformations.

Using a computer science terminology, we could paraphrase the above quotation saying that styles act like a *type system* for the domain of artifacts, seen from the point of view of their aesthetic characteristics.

2.2 Ontological level

From a philosophical standpoint, an *ontology* is an account of the categories of entities that exist or may exist in some domain, according to a given view of the world. As such, an ontology does not depend on a particular *language*: it is what is usually referred as an *(intensional) conceptualization* [56] in Artificial Intelligence literature.

A *formal ontology* is a logical theory that accounts for the intended meaning of a formal vocabulary, enforcing the commitment to a particular conceptualization, by constraining (usually in an approximate way) the intended models of a logical language that use such vocabulary. Henceforth, I will always refer to formal ontologies, even when I use the term ontology without other qualifications.

A formal ontology is usually specified by a collection of names for entity and relation types, organized in a partial ordering by the subsumption relation.

My first aim is to embed the taxonomy of artifacts sketched in Section 2.1 in a top-level ontology, such as DOLCE [98], with the goal of devising an ontology of the domain of artifacts. Such ontology, like DOLCE, will be an ontology *of particulars*, in the sense that the entities in the domain of discourse can not have instances; *universals*, that is, entities that can have instances, are used in the ontology, but only as a mean of organizing and characterizing particulars.

The subsumption relations have a prominent role in the resulting ontology, and order artifacts mainly on the basis of their structural and functional characteristics (in the same way they are ordered in industrial catalogs), but nevertheless they do not provide much help with the task of organizing the artifacts according to their aesthetic styles. In fact, it is often the case that:

- entities that are structurally and functionally very different may have a very similar style (e.g., in the sub-domain of clothing, a shirt and a pair of trousers both of colonial style);
- conversely, entities that are structurally and functionally very similar may have very different styles (e.g. two models of cars, both in the B segment, with a diesel 110 hp engine may be stylistically very different, whereas a small utility car and a luxury car of the same producer may share relevant aesthetic choices);
- some special entities have an unique set of aesthetic properties (e.g., the wedding dress of Lady Diana Spencer[3]).

Organizing the domain of artifacts according to their styles means, in fact, to provide a suitable characterization of *stylistic similarity*. Thus, I will analyze some relations that I believe to be important for the analysis of similarity between styles: *prototypicality*, *materialization*, *part-of* and *(semiotic) signification*.

2.2.1 Frame-based representation systems

The formal ontology I aim to develop will be specifically designed to be implemented within a frame-based representation system (FRS). The rationale behind this choice is the fact that FRSs are the long term *de facto* standard approach for knowledge base exchange and processing in most industrial applicative settings. Here, I give only a brief account of the most common features of FRSs; see [82] for a more in-depth analysis of design and implementation choices.

Frame-based representation systems organize knowledge in an 'object-oriented' way, as a network of *frames* and *slots*. (Instance) frames are uniquely identifiable entities which represent individuals in the conceptual world. Slots are mappings from frames to a set of values, and model facts about the individuals (as binary relations). A value can be a frame, or an element of a concrete domain (such as integers, reals, strings). Furthermore, FRSs model terminological facts with assertions on unary predicates defined on frames, which organize individuals into a taxonomical hierarchy of classes.

FRSs are thus constrained to use only constants (individuals), and unary and binary relations, although n-ary relations can be indirectly modeled, by reifying them into n-slot frames. These limitations (along with the fact that the conceptual model is constrained to first-order logic) will result in important properties in the logical and computational layer. I introduce them here only to justify the fact that the ontological choices discussed in the following subsections are somehow 'optimized' with respect to these limitations.

2.2.2 Prototypes

In general, a *prototype* is an instance that combines the most representative features of a category, and is used as a cognitive reference point for the categorization of "less representative" or "weaker" instances. In the domain of artifacts the term is used with a stronger sense: prototypical instances historically predate other instances and act as an ideal model for them. The notion of prototype is ubiquitous in Art History and Design Theory, and it is nearly always used to deal with aesthetic properties.

Lakoff [92, 93], building on Rosch's *Prototype Theory*, describes a number of so-called *prototype effects*, that is, evidences that prototypes have an important role in the way

[3] This example is from Umberto Eco, originally explaining the case, in semiotic terms, of a *type* with a single *token*

human beings perform categorization tasks[4].

Frame-based representation systems offer an approach to prototype representation that is compatible with Rosch's theory, based on the assumption that prototypes can be represented as a collection of relevant features [46].

The set of instances that share the same prototype is a *radial category*. A radial category, as defined in [92] is

> [...a category] structured radially with respect to a number of its subcategories: there is a *central* subcategory, defined by a cluster of converging cognitive models [...]; in addition, there are *noncentral extensions* which are not specialized instances of the central subcategory, but rather are variants of it [...]. These variants are not generated from the central model by general rules; instead, they are extended by convention and must be learned one by one. But the extensions are by no means random. The central model determines the possibilities for extensions, together with the possible relations between the cental model and the extension models.

A radial category is different from a class in the meaning in which this term is intended in Knowledge Representation. The strict qualification of a class is the existence of a single equivalence relation that defines the class in extensional terms, whose intensional counterpart is a list of properties that the elements of the class have in common. In a radial category, the extensional structure is identical, but the description at the intensional level is rather different. A radial category can be seen as a graph in which a prototype is similar to other individuals in one sense, and these individuals are similar to other individuals as well. Each step in the graph is justified by the sharing of a set of properties (or of the values of a shared property). However, two individuals that are similar to the prototype do not necessarily share the same properties with each other.

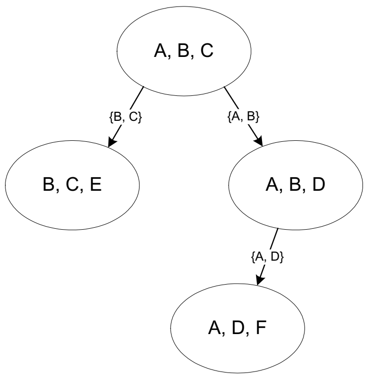

Figure 3. An example of Radial Category

As an example, suppose that A, B, C, D, E, F are unary predicates that represents 'primitive' properties. The class of the individuals that satisfy the property

$$(A \wedge (B \wedge (C \vee D)) \vee (D \wedge F)) \vee (B \wedge C \wedge E)$$

can be expressed as the radial category depicted in figure 3, where each node of the graph represents a set of individuals that satisfy a set of primitive properties, and each edge represents a prototypicality relation that 'propagates' a set of properties (edges are directed since prototypicality relations are anti-symmetric).

Primitiveness of properties is here intended as an informal concept, strictly connected with the level of granularity of the language, level which should be chosen in a context- and domain-dependant way in order to guarantee the adequacy and the user-friendliness of the language itself. When the right level of granularity is chosen, both nodes (set of individuals) and edges (prototypicality relations) can naturally receive meaningful names, whereas the correspondent subsumption-based class hierarchy would usually require the introduction of spurious classes, not easily mappable to the natural terminology of the users.

Since styles are commonly defined by means of prototypes, I believe that radial categories are a suitable tool for the classification of artifacts according to their styles. Below, I propose a characterization of the notions of prototype and radial category that, although quite general in its scope, is specifically tailored to my domain of interest.

In the domain of artifacts, $Prototype(x, p)$ specifies that p is a prototype for x. *Prototype* is a subset of a more general dependence relation D_a, that express the constraint that the maker of the artifact x must have known the artifact p when s/he planned the making of x. A formal characterization of D_a that accurately describes the above informally expressed meaning is a complex issue, however it is reasonable to assume that D_a is a *functional dependence* relation, and thus anti-reflexive and not necessarily transitive (since the maker of an artifact does not need to be aware of the prototype of the prototype, and in fact this object might not be a suitable prototype for the new artifact),

(D.1) $\neg D_a xx$ (*anti-reflexivity*)

and anti-symmetric (due to the temporal ordering implicit in the informal definition)

(D.2) $(D_a xy \wedge D_a yx) \rightarrow x = y$ (*anti-symmetry*)

Associated to each specific relation of prototypicality $P \subseteq$ *Prototype* there are a finite set of binary relations $IA_P = \{\phi_1, \ldots, \phi_n\}$ (inherited attributes of P) and a finite set of unary relations $IT_P = \{\psi_1, \ldots, \psi_n\}$ (inherited types of P), such that:

$$P(x, y) \wedge \phi_i(y, z) \rightarrow \phi_i(x, z)$$
$$P(x, y) \wedge \psi_i(y) \rightarrow \psi_i(x)$$

This model only specifies the necessary properties of a prototypicality relation; these constraints are meant to safeguard the consistency of the relations themselves. So it is not possible, in general, to devise algorithmically the prototypicality relations defined on a set of individuals, from the features of the individuals themselves. This is compatible with Rosch's theory, which maintains that prototypicality is a cognitively

[4] In fact, Rosch maintained that prototype theory was neither a suitable theory of information-processing psychology, nor a plausible model of actual mental representations; but this is not a problem for my ontological effort, since I aim to model not scientific knowledge, but commonly used conceptualizations.

and culturally constructed convention, rather than an inherent property of individuals.

A radial category R is defined by a finite set of individuals c_R (the *center*), and a finite set of prototypicality relations $P_R = \{\pi_1, \ldots, \pi_n\}$; R is the smallest set such that:

$$x \in c_R \rightarrow x \in R$$
$$x \in R \wedge (\bigcup \pi_i)^*(y, x) \rightarrow y \in R$$

R is composed by the center, and by the individuals reachable from the center with the transitive closure of the union of the involved prototypicality relations. Both c_R and P_R can be chosen arbitrarily (i.e., they can not be inferred from individuals' properties) and are the product of cognitive and cultural conventions. This definition can be easily expressed in first-order logic.

An interesting theme is the ontological analysis of the different kinds of prototypicality relations, in order to devise a taxonomical organization, based on the kinds of attribute and types that are propagated.

Franconi et al. [46] provide a quantitative similarity model for the relation between a prototype for a class of individuals and a generic instance of that class, both represented with a feature-based approach; the model takes into account some peculiar properties of human similarity judgement: the fact that common features have more weight than distinctive features, the fact that the subject of the comparison usually has a greater importance than the referent, and context dependency.

2.2.3 Materialization

Informally, *Materialization*(c, a) [38, 106] relates a more concrete individual c to a more abstract individual a which partially describes it.

As an example, *The New York Times* is a materialization of *newspaper*, *today's issue of The New York Times* is a materialization of *The New York Times* and *this copy of today's issue of The New York Times* is a materialization of *today's issue of The New York Times*.

Working within an ontology of particulars, I formally define materialization as a relation between instances, where *abstractness* (and conversely, *concreteness*) is a partial ordering on instances, and is not related with the meta-level notion of *instantiation*.

A subset of the properties of the more abstract individual are inherited by the more concrete one. Dahchour et al. [38] take into account only the inheritance of properties with concrete domains values, whereas the inheritance of the relations with other individuals is more problematic. As an example, if we consider a *Car* instance which is a materialization of a *CarModel* instance, it seems plausible to assert that the *Car* instance inherits the *length* property of the *CarModel* instance, whereas it seems incorrect to assert that the *Car* instance's engine is the same as the *CarModel* instance's engine, since the word *engine* is used with two different senses: the former denotes an object that is the materialization of the object denoted by the latter.

I propose a characterization of Materialization based on prototypicality relations. Associated to each specific materialization relation $M \subseteq Materialization$, there are a relation $P_M \subseteq Prototype$, and a relation PI_M (prototypical instances for M), which relates each materialized individual with its prototypical instance such that:

$$M(c, a) \rightarrow \exists pi_a(PI_M(a, pi_a) \wedge P_M(c, pi_a))$$

In general, prototypical instances are expected to be less in number than concrete instances, usually one for each abstract instance. Inheritance from prototypical instances to concrete instances is generally not problematic, since they are at the same abstraction level.

The study of composition between PI_M relations and meronymic relations (see Subsection 2.2.4) would be an interesting theme of study.

What makes materialization interesting from the point of view of the study of aesthetic similarity, is that stylistic properties and stylistic constraints are often propagated through the materialization relation, from more abstract entities to more concrete ones.

Continuing the example, a *newspaper*, as an artifact, has some specific stylistic constraints: it is made of thin paper, the text is placed into columns, there is the masthead on the first page; *The New York Times* inherits those constraints and adds its own specific masthead, an ISSN (International Standard Serial Number; a unique eight digit number assigned to every serial publication), specific constraints in the page layouts, specific typographical fonts, a policy for the choice of the wording in the headlines and for the admissibility of the photographs, and so on; *today's issue of The New York Times* has a specific page layout that optimally displays the news of the day while satisfying the above mentioned stylistic constraints, but it does not have a specific ISSN.

An example with the Fashion industry. A more complex example, that involves the use of both radiality and materialization, is related to the notion of style as it is used in the Fashion industry.

If we take into consideration the most prominent fashion houses, like, say, Armani or Versace, it is clear that there exist a very abstract, but yet collectively recognized notion of "Armani style" and "Versace style" (in the common use, these entities are usually specialized by gender, so people talk about "the Armani man" or "the Versace woman"). These entities are not merely a set of stylistic constraints, but actually embody a set of core aesthetic values, and they even imply a characterization of the psychology of the person that is going to wear the clothes, rather than of the clothes themselves. They are usually exemplified by prototypical milestones in the history of the fashion house, often the original collections of the house's founder or the ones perceived as the most innovative.

These 'paradigms' are materialized two times a year with the *collections*. From the stylistical standpoint, a collection is another abstract entity, since it may contain very different models, yet it is unmistakeably recognized as an unity by domain experts. In fact, when a fashion expert talk about the past, s/he refers more often to collections rather than to specific models. What is important, is that a collection is not a mere implementation of the house style, but is an interpretation of the house's core values in the current social, economical, and even ethical and political context. Some core values may even be temporarily negated or hidden (and this is what is usually maintained as most interesting by fashion magazines). This is an example of radiality: each collection is related to the paradigm, but the set of features that constitute the link is continually evolving.

The next step of materialization, which is also another radial step from the paradigm, is the relation between a collection and its models. Models can be so different that is not possible to devise a single feature common to all of them, but still recognizable as part of the collection, and expressing the core aesthetic values of the house.

2.2.4 Mereology

Mereology is the theory of *parthood* relations: of the relations of part to whole and the relations of part to part within a whole [127]. An account of the subject from the standpoint of Knowledge Representation can be found in [7] and [6].

General Extensional Mereology (GEM) is a commonly accepted view on the theory of parts and wholes. It introduces a Pxy binary relation, which states that x is a part of y. P is a partial ordering, and thus is reflexive, antisymmetric and transitive.

(M.1)	Pxx	(*reflexivity*)
(M.2)	$(Pxy \wedge Pyx) \rightarrow x = y$	(*anti-symmetry*)
(M.3)	$(Pxy \wedge Pyz) \rightarrow Pxz$	(*transitivity*)

Overlap (O), *Underlap* (U) and *Proper Part* (PP) mereological predicates are defined from P.

$$Oxy =_{df} \exists z(Pzx \wedge Pzy) \quad (\textit{Overlap})$$
$$Uxy =_{df} \exists z(Pxz \wedge Pyz) \quad (\textit{Underlap})$$
$$PPxy =_{df} Pxy \wedge \neg Pyx \quad (\textit{Proper Part})$$

GEM places a set of additional constraints on P:

- Extensional identity. Two individuals are identical if and only if they have the same parts.

  (M.4) $\forall z(PPzx \wedge PPzy) \rightarrow x = y$

- Mereological sum. There always exists the individual composed by any two individuals of the theory.

  (M.5) $Uxy \rightarrow \forall z \exists w(Owz \leftrightarrow (Owx \vee Owy))$ (*Sum*)

- Supplementation: If an individual x is a proper part of an individual y, then a different individual z exists which is the missing part from y. The following axiom express this intuition in a stronger way, that works well even with non-spatial domains.

  (M.6) $\neg Pyx \rightarrow \exists z(Pzy \wedge \neg Ozx)$ (*Supplementation*)

Both philosophical research [102] and psychological experimentation [49] maintain that similarity in general (and aesthetic similarity in particular) is not a trivially compositional property. In fact, similarity is not even symmetric: as an example, people asked to quantify how much a pear is similar to an apple, will consistently answer differently than people asked to quantify how much an apple is similar to a pear [125].

The formal properties of different specific kinds of part-whole relations, such as *Component*, *Member*, *Segment*, *Quantity*, *Stuff*, *Ingredient* have been studied (see [7, 114] for references), and constitute a top-level ontology of part-whole relations, which will be the starting point for a further analysis of these kinds of relation in the domain of aesthetic properties.

Of particular interest, is the study of the properties of the composition of these specific relations. In general, these part-whole relations are not closed under composition, as in the following example (taken from [7]).

> An arm is part of a musician, the musician is part of an orchestra, but it would sound a bit strange to state that the arm is part of the orchestra;

In this case, the word *part* is used with two linguistically different senses, *Component* and *Member*:

Component(arm, musician)
Member(musician, orchestra)

but we can not infer that *Member*(arm, orchestra), since $\textit{Member} \circ \textit{Component} \not\subseteq \textit{Member}$.

Another example, more related to aesthetic properties, is the following:

> Silk is smooth. Thus a blazer made of silk is smooth. But we can not say that a suit composed by a silk blazer and worsted wool pants is smooth.

This can be modeled as follows:

Smooth(silk)
Stuff(silk, blazer)
¬*Smooth*(worsted wool)
Stuff(worsted wool, pants)
Component(blazer, suit)
Component(pants, suit)

Smooth is a kind of aesthetical (more specifically, tactile) attribute that is preserved by the *Stuff* relation, but not by the *Component* relation. Thus we can infer that the blazer is smooth, but not that the suit is smooth.

Of course this is only a toy example: on one side, to effectively model tactile attributes many more aspects need to be taken into consideration; as an example, only touchable parts need to be considered, and an individual is smooth if and only if all its touchable parts are smooth. On the other side, more refined meronymic ontological analysis than the top-level distinction between *Stuff* and *Component* may be necessary.

It is thus important to study up to what extent, and in which cases, aesthetic properties of a part of an artifact propagates to and/or influence aesthetic properties of the whole artifact.

2.2.5 Semiotics

In its broadest definition, *Semiotics* is the study of signs, where a sign is anything that 'stands for' something else [29].

A formalization of the relation of *signification*, that relates signs to other signs that connotate their intended meaning could help the analysis of culturally constructed aesthetic features. In particular, I am interested in an ontological analysis of *modes of relationship* between signs and *rhetorical tropes*.

The following classification of modes of relationship between a signifier and a signified has been originally introduced by Pierce [105]:

- **Icon** is a mode in which the signifier is perceived as resembling or imitating the signified;
- **Index** is a mode in which the signifier is directly connected (physically or causally) to the signified;
- **Symbol** is a mode in which the signifier is connected to the signified only by an arbitrary convention.

Rhetorical tropes classify the way signs are used to express *figurative meanings* (as opposed to *literal meanings*). The most important rhetorical tropes are:

- **Metaphor**, which involves a literal subject expressed in a term of a figurative subject that bears a resemblance (either iconic or symbolic) with the first subject;
- **Metonymy**, which involves a literal subject expressed in a term of a figurative subject that bears a contiguity or a causal or functional relationship with the first subject, that is, a substitution of a part for the whole, effect for cause, place for event, and so on.

To the best of my knowledge, no formal ontological analysis of those concepts has been devised. However, there are many accounts on this subjects, from an Human Studies standpoint, especially related to visual media, that provide a solid – even if methodologically very different – theoretical foundation. See [53, 91, 71, 12, 84, 103, 100, 101].

2.3 Logical level

The most prominent issues I need to deal with in the logical layer are the following:

- How to represent the instances of the domain, i.e. (mainly) artifacts.
- How to intensionally characterize sets of instances that share the same (aesthetical) style, i.e. radial categories (of artifacts).
- How to relate these choices to the computational implementation.

Since the language is developed with frame-based representation systems as the main implementation target, I believe that Description Logics (DLs) are a good choice for the underlying logical framework, since they are well suited to give an account of frame-based (and, more generally, network-based) representation structures, in term of a formal logical semantics.

As a generic knowledge base system has both a general, intensional knowledge about the application domain, and a specific, extensional knowledge about the application instance, so a DL knowledge base is composed by a terminological component (*TBox*) and an assertional component (*ABox*). The TBox specifies the vocabulary of the application domain, by means of atomic concepts (sets of individuals in the domain), atomic roles (binary relations between individuals), and a restricted set of epistemologically adequate constructors used to define complex roles and concepts from the simpler ones. The ABox contains assertions about named individuals (i.e. constants) in terms of the vocabulary defined in the TBox.

Given a DL knowledge base, a number of different kinds of reasoning tasks can be performed, both on the terminological level, such as checking if a concept is satisfiable, if a concept subsume another concept, or if two concepts are equivalent or disjoint, and on the assertional level, such as checking if a set of assertion are consistent, or if an individual is an instance of a specific concept.

There is a trade-off between the choice of a more or less expressive set of concept constructors, and the decidability, or the computational tractability, of the above mentioned reasoning tasks.

The Description Logic $\mathcal{SHIQ}_+(\mathcal{D})^-$ seems a good choice as the ontology language for aesthetical knowledge representation. It supports the following features:

- role intersection ($R \sqcap S$), union ($R \sqcup S$) and complement ($\neg R$);
- existential restriction ($\exists R.C$) and value restriction ($\forall R.C$);
- inverse roles (R^-), transitive roles (R_+) and role hierarchies ($R \sqsubseteq S$);
- qualified cardinality restrictions ($\leq_n R.C$) and ($\geq_n R.C$);
- acyclic role inclusion (restricted to the form $R \circ S \sqsubseteq R$ and $S \circ R \sqsubseteq R$);
- concrete datatypes (i.e. concrete domains restricted to unary predicates and predicate restrictions without role chains).

Inference problems in $\mathcal{SHIQ}_+(\mathcal{D})^-$ are EXPTIME-complete in the worst case, but 'practicable' in the average case (see Subsection 2.4.1).

What makes this choice still more interesting is that many languages used in the industry for the manipulation of knowledge bases (such as *OWL* and *RDF Schema*, see Subsection 2.4) can be studied within this framework. In fact, OWL would also require *nominals*, i.e. concepts representing a singleton set consisting of one individual, but support for this feature would significantly impact the tractability of inference problems.

Concerning the issue of the intensional representation of radial categories, I will explore the idea of using an approach based on generative grammars. However, this approach is problematic, because DLs that contain context-free Grammar Logics are undecidable.

Cardelli et al. [24] maintain that:

> Traditional type systems are grounded on mathematical constructions such as cartesian products, disjoint unions, function spaces, and recursive types.
>
> The type systems for semi-structured data, in contrast, resemble grammars or logics, with untagged unions, associative products, and Kleene star operators. The theory of formal languages, for strings and trees, provides a wealth of ready results, but it does not ac-

count, in particular, for functions. Some integration of the two approaches to type systems is necessary.

This research direction is to some extent connected with the idea of devising a framework for expressing structured explanation of aesthetical judgements, as described in Subsection 2.5.

2.4 Implementation level

The most natural way to implement the language of aesthetic styles in a machine-usable form, is to follow the recommendations of the Semantic Web Initiative (SWI) [32] of the World Wide Web Consortium (W3C). This initiative aims to develop both a set of language specifications and a distributed architecture model, with the intent of enabling the publication of machine-understandable metadata on the Web. The current components of the SWI framework are the *RDF Core Model*, the *RDF Schema language* and the *Web Ontology language* (OWL).

The Resource Description Framework (RDF) [33] is a language for representing metadata about Web resources. Entities are identified using Web identifiers (called *Uniform Resource Identifiers* [17], or *URIs*), and resources are described in terms of simple properties and property values (constants or URIs). This enables RDF to represent simple statements about resources as a graph of nodes (representing resources, and property values) and arcs (representing properties). RDF also provides an XML-based syntax (called *RDF/XML*) for recording and exchanging these graphs.

RDF Schema [35] provides the facilities needed to describe vocabularies of domain- and application-specific resource classes and properties, with a semantics for generalization-hierarchies.

OWL [34] builds upon RDF Schema, adding a specific vocabulary for further describing properties and classes, introducing constructs to specify, among others, relations between classes (e. g. disjointness), cardinality constraints, equality, richer typing of properties, special characteristics of properties (e. g. symmetry), and enumerated classes.

Although those languages have been specifically designed to be used on the World Wide Web, they may be easily retrofitted to work in conjunction with proprietary industrial settings; in particular XML has become the de-facto standard for the exchange of structured and semi-structured data between applications, and the XML Namespaces facility [31] makes it straightforward to extend an existing XML Schema in order to add metadata.

An architecture proposal for a Knowledge System that implements the features discussed in this proposal and make them available to both human users and automated agents is pictorially sketched in Figure 4. What makes the cooperation of such heterogeneous pieces of software possible is the common conceptual model based on a frame-based knowledge representation system that more or less explicitly adheres (or can be constrained) to the $\mathcal{SHIQ}_+(\mathcal{D})^-$ logic, which is also the foundation of the SWI framework.

Protégé [77] is an ontology development environment that can import and export knowledge bases using a number of more or less standardized formats, including RDF, RDF Schema and OWL. *Algernon-J* [70] is an expert system shell with a rule-based inference system. *Protégé* and *Algernon-J* provide two abstract Application Programming Interfaces (APIs) to exchange frame-based knowledge bases, that, although are mutually incompatible on the implementation level, are based on the same conceptual model, and thus can be easily bridged using a software interface layer[5].

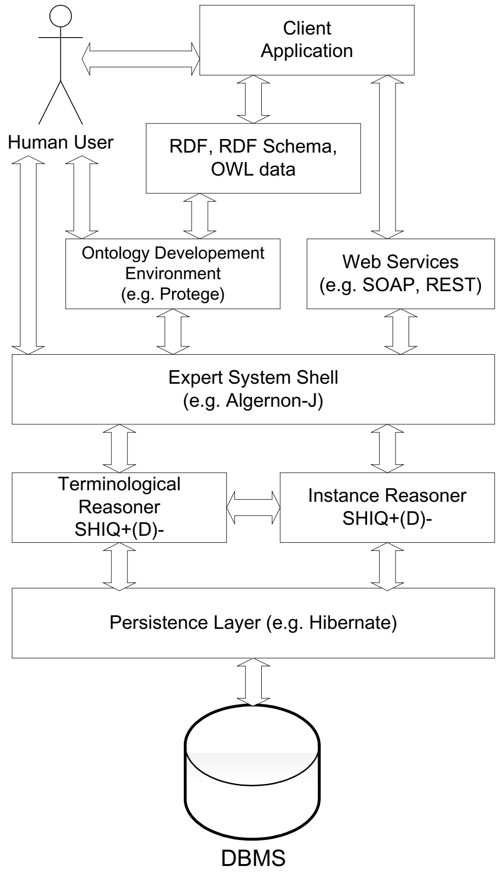

Figure 4. Knowledge System Architecture

Algernon-J's build-in engine uses forward and backward chaining rules to perform inference on frame-based knowledge bases. A rule has an antecedent and a consequent part; both are a conjunction of simple clauses: when antecedent clauses are satisfied by the current state of the KB, consequent clauses are used to update to the KB. A clause can extensionally specify either a relationship between two frames, or the type of a frame; furthermore it can call an external function, written in an embedded general-purpose programming language, such as Java or LISP. Although this engine is obviously complete from the point of view of expressiveness, it does not directly exploit, at the language level, some important features of the KS's underlying model, namely $\mathcal{SHIQ}_+(\mathcal{D})^-$'s support for intensional terminological inference and for specific concrete domains. Thus, in order to provide a more suitable inference engine, *Algernon-J* support for external extensions may be used to embed a $\mathcal{SHIQ}$-like reasoner, and possibly some other domain-specific reasoners.

There exists a pseudo-standard web services protocol for

[5] Such layer is already provided with *Algernon-J*, that can be directly invoked from within *Protégé*

the exchange of frame-based knowledge bases, the *DIG Description Logics Interface* [14], and many of the existing $\mathcal{SHIQ}$-like reasoners (such as *FaCT* [72] and *RACER* [64]) implements it.

What is still missing is a persistence layer that is both open and capable of handling very large knowledge bases; in my opinion a good choice would be to use an open-source object-to-relational persistence layer, such as *Hibernate* [54], and then rely on an enterprise-strength open-source relational DBMS, such as *Postgres* [16]; a software interface layer needs to be developed to bridge Algernon-J's abstract API for knowledge base sharing with the persistence layer.

Client Applications can interact with the Knowledge System both directly through a web service interface, and indirectly, by exchanging information using standard W3C formats. Users can both interact directly with the system, using an Ontology Development Environment such as *Protégé*, or use the applications powered by the system.

2.4.1 Performance issues

Although the worst-case complexity for the satisfiability test in $\mathcal{SHIQ}_{+}(\mathcal{D})^{-}$ logic is EXPTIME-complete [124], many optimizations have been devised, that handle the more common patterns of usage in an efficient way, thus making $\mathcal{SHIQ}_{+}(\mathcal{D})^{-}$-based knowledge systems suitable for a wide array of real-world applications. In particular, *RACER* appears to be the most optimization-savvy of these systems, and exhibits a number of success stories in various industrial settings [64]; however it is a closed-source proprietary project.

Optimization techniques for the algorithms for ABox and TBox reasoning with $\mathcal{SHIQ}_{+}(\mathcal{D})^{-}$ are described in [68, 66, 65]. Specific implementation issues for very large knowledge bases are addressed in [69, 67].

2.5 Representation of Aesthetic Judgement Justifications

The problematic nature of *aesthetic judgement* has been explored in depth by Immanuel Kant in the *Critique of Judgement*, and can be summarized with the following fundamental antinomy [81]:

> The judgement of taste is not based on concepts; for, if it were, it would be open to dispute (decision by mean of proof). [...however] the judgement of taste is based on concepts, for otherwise [...] there would not be room even for contention in the matter, or for the claim of necessary agreement of others.

On one hand, aesthetic appraisal is inherently connected with a first person sensorial experience (hence the use of the word 'aesthetic', with the etymological meaning of 'related to the senses'), and is immediate, without the need of a conceptualization of the perceived object.

On the other hand, the expression of an aesthetic judgement implicitly claims an universal validity; both in the common use of the natural language, and in Art Theory, the attribute of *beautiful* is not intended as a property of the observer, but as an inherent property of the object. If we compare the following statements:

1. **X** is beautiful;
2. **Y** likes **X**.

we can see that they have different meanings. When we say that something is *beautiful*, we expect this property to be universally recognized, that is, that everyone ought to like the object, whereas when we say that we like something, we stress that we are expressing only a personal preference, and we are describing a feature of ourselves. It may be even the case that we dislike something that we consider beautiful, or that we like something we do not consider beautiful.

Thus, the aesthetic evaluation process has two phases that mutually interact cyclically: the object is subjectively and directly experienced, and then its characteristics are examined in order to isolate the features that give ground to the feeling arisen from the experience.

I am interested in giving an account of the product of the second phase, that is a *justification* of the aesthetic judgement.

The judgement itself is seen as an *arbitrary* decision, that is, a decision that is the result of the evaluation of a choice problem that involves the analysis of multiple strictly incompatible criteria. In this context, the results of the commonly used (multiple-criteria) Decision Theory [21, 9, 10, 62, 27] are not of much help, since the criteria cannot be merged by means of a common utility function. So, in order to reach a decision, some criteria must be *arbitrarily* disabled, and/or some possible choices must be *arbitrarily* rejected.

The focus of the investigation is not placed on the decision process (which, being arbitrary, is left to the human being), but on the generation and representation of the *justifications* for the decision taken. In particular, justifications can be characterized in different ways, and different kinds of optimality can be defined, according to the intended use of the justification itself. A very preliminary investigation of this subject is reported in [37].

3 Applications

I expect the results of the proposed research activity to have a positive impact on the following applicative domains: Cooperative Design (outlined in Section 3.1), Collaborative Recommendation Systems (outlined in Section 3.2), and Semantically-augmented Databases (outlined in Section 3.3).

3.1 Cooperative Design

Industrial Design is an intrinsically multi-disciplinary activity: it requires specific expertise from engineering disciplines (such as Information Technology, Electronics, Mechanics, evaluation of materials, analysis of manufacturing process, Ergonomics), economical disciplines (Management, cost analysis, customer relationships handling), humanistic disciplines (Psychology, Sociology), and artistic disciplines (Aesthetics, styling, Graphical and Plastic Design, analysis of fashion trends).

Domain-specific knowledge corpora are growing in size, and both engineers and designers are becoming more and more specialized.

In this scenario, the main goal of a knowledge-based system is to enable and organize the exchange of information between the human subjects involved. However, the focus of the state-of-the-art knowledge-based systems is toward quantifiable and functional elements of design, thus neglecting the more arbitrary, humanistic ones, which depends on individual and collective tastes.

An interesting approach toward these goals, is expressed in [111]. In this work, Rodgers et al. have addressed the problem of managing aesthetic knowledge using the notion of *explanation*, defined as a set of human-entered attributes and descriptions. What I believe is missing in their investigation, is the *ontological level* of this knowledge management. An ontology of aesthetic aspects in Design is necessary in order to make software tools like their prototypical application WebCADET© useful in practical cases, and put on the bases for the construction of an aesthetics-aware Semantic Web.

I believe that a system able to support aesthetic reasoning would be fruitfully employed in semantically-augmented design tools and collaborative systems, that is, applicative domains where human communication and knowledge sharing can be empowered by aesthetic judgements that are transparent for the user, and that can be made fully explicit, and thus modifiable, quotable and re-usable.

3.2 Collaborative Recommender Systems

Recommender Systems (RS) [109, 115] try to replicate the natural social process of "word of mouth" recommendation. The system is expected to suggest items in a specified domain, based on users' history, judgements, and specific preferences. Specific RSs have been developed to suggest books, movies, books, songs, and other kinds of items, all of them strongly characterizable in term of aesthetic properties.

In a typical RS, users provide recommendations as inputs, which are subsequently aggregated by the system, and presented to other users upon request. RSs play an important role in e-marketplaces (ebay.com, amazon.com) and peer-to-peer file sharing networks (eMule, Gnutella), where users not only express judgements explicitly, by voting polls or filling evaluation forms, but also implicitly, buying an item or choosing a file to exchange.

RSs try to generate suitable recommendations using the following sources of information:

1. items' metadata, both human-edited (such as *title* and *author* for books), and automatically extracted (e. g. natural language documents similarity, computed using metrics based on word frequencies);
2. items' placement in a predefined taxonomy, as a way to infer items' similarity from categorial similarity;
3. user model, inferred by both user's history and explicit user's preferences;
4. user's placement in a cluster analysis of the community of the users, performed to identify recurrent patterns of preferences (even if the sparseness of the data is often a problem).

I believe that a representation of the aesthetic properties of the items, as well as a representation of the aesthetic judgements and the aesthetic tastes of the users, would greatly improve the effectiveness of these sources:

1. an item may be preferred for a number of different reasons: an explicit description of its aesthetic characteristics should make it easier to identify the specific traits that have driven users' choice;
2. commonly used taxonomies are built on *is-a* relationships based on items' functional purpose or manufacturer's categorization, whereas the aesthetic properties that drive users' choices are transversal with respect of that kind classification: a kind of wine is aesthetically near to a certain kind of food, a kind of shoes is stylistically near to a specific kind of suit;
3. more refined items' metadata lead to more accurate user preference and taste models extracted from users' history;
4. it becomes possible to aggregate tastes rather than items; this makes sparseness less relevant, since an item with no usage or purchasing history can be related to aesthetically similar items.

But the most important advantage is that it becomes possible for the RC to *justify* the suggestions in terms of (aesthetic) traits of the suggested items, and thus the user can reject less than satisfactory choices without personally checking the referred item (by purchasing or downloading it), but on the sole basis of the description of the motivations of the recommendation.

3.3 Semantically-augmented Databases

Some kind of users (industrial designers, marketing researchers, exhibition curators) routinely need to browse large databases that catalogue items with a rich set of aesthetics properties.

A semantically-augmented aesthetic knowledge system would provide markup of aesthetic nature, so that we can imagine search features able to process the following requests:

- *Look for color combinations for female clothing that express a daring and authoritative mood, and that have been used in the spring-summer collections of this year of the most prominent Italian fashion stylists.*
  (Color Trend Analysis is a specific area of Marketing Analysis, that traces the industrial use of specific colors and tries to forecast future trends of color usage.)
- *Look for paintings that represent Napoleon Bonaparte as a General.*
  (As opposed, for example, to those which represent him as Emperor, or as a young boy, or while in exile; looks for denotations and connotations of Napoleon's clothing and garments in the paintings)
- *Look for covers of records published in the year 1997 which contain figurative elements that cite the graphical style of the culture of the American 'hippy' movement in the sixties.*
  (Looks for specific clothing or hairstyles of depicted people, spiraling decorative patterns, rainbow or psychedelic color gradients, specific typographic fonts (usually scripts), marijuana leaves and so on. All these items denote and/or connote to same extent the hippy culture. It is important to notice that these 'citations' willingly reproduce as icons some graphical themes that forty years ago were virtually imposed by the limited typographic technologies of those days: for example, writings along curved lines were hand-drawn.)

4 Related work

The references to take into consideration are many, and different for scope and aim: Design Studies, Philosophy, Psychology, Cognitive Science, Art Theory, Semiotics, Knowledge Representation. The common thread I would like to follow is the existence of an explicit, and conscious logical-mathematical definition of the content. Also, I will deal mainly with conceptualizations that consider beauty an attribute of the object itself, rather that an attibute of perception. In Section 4.1 I will relate the cited works with my proposed approach.

Although the term *Aesthetics* has been introduced by Alexander Baumgarden only in 1735, the philosophical quest for the principles of artistic beauty and taste has been a constant presence in the history of the western thought.

Aristotle (384–322 BCE) was perhaps the first to enumerate a list of formal properties that he maintained to be characteristic of beautiful objects: symmetry, order and exactness (*Metaphysics*, XIII).

Even earlier, Pythagoras (ca. 532 BCE) introduced the concept of *harmony*, based on the discovery of the fact that specific constant proportions between measures (in particular the *golden section*, see Section 2.1.3) are perceived as pleasurable. The notion of *proportion* had a deep impact not only on ancient Greeks, but also on Romans (such as Vitruvius), on Middle Ages' scholars (such as de Honnecourt and Cesariano), and Renaissance's artists and philosophers (such as Leonardo da Vinci and Leon Battista Alberti), who used proportion as the main formal tool to explain the beauty in the harmony of the human body, of nature, of architecture and of other artifacts.

In 1928, George David Birkhoff proposed the first mathematical model of the aesthetic value of artifacts:

$$\text{esthetic value} = \frac{\text{amount of order}}{\text{complexity of the artifact}}$$

Although the elements on the right side of Birkhoff's equation were, to say the least, not well defined and difficult to measure, even on a rudimentary level, on real-world artifacts, this model was taken as the basis of a lot of research, mainly within the German Bauhaus industrial design school. Different models of structural complexity were proposed, and the Birkhoff's model was tested in a number of psychological experiments.

In 1933 Birkhoff introduced the hypothesis that the feeling of aesthetic pleasure is originated by the very effort and success in perceiving the features of the artistic objects.

In 1956, Abraham A. Moles proposed an elaboration of Birkhoff's hypothesis, that related aesthetic value with the degree of surprise of the observer. He maintained that:

> A work of art is an object or a performance that gives a human being a possibility to use his perception ability at a maximum.

As explained in [113]:

> If the observer of a work of art has an expectation, his impression of the work seldom corresponds to the expectation exactly. The difference can be called a difference of expectations. If this difference is too small, the result will be that the work gives a trivial impression. If, however, the difference is too large, the work of art may remain totally incomprehensible. Only when a work of art differs from the expectations to a suitable degree, is the aesthetic impression positive.

Structural Information Theory (see Section 2.1.3) is a formal calculus that has been used to some (limited) extent to model these informal notions of complexity, expectation and surprise.

Gregory Stiny introduced [122, 121] the notion of *Shape Grammar* as a tool to model the process of graphic and plastic design. A *shape* is any finite arrangement of points, line segments or bounded surfaces and solids. A shape grammar, similarly to the constructive context-free grammars used in linguistics, is a set of productions, called *shape rules*; each shape rule matches a class of shapes and replaces each instance with another shape. Algebraically, a shape rule operates under a group, usually the Euclidean group.

Knight [88] used shape grammar as a basis for a formal model of stylistic transformation in both abstract paintings and architecture.

Williams [134] developed an aesthetic theory based on the assumption that aesthetic response to works of art is proportional to the level of complexity perceived, and the level of 'surprise' experienced by the observer.

The FIORES and FIORES-II projects (Formalization and Integration of an Optimized Reverse Engineering Styling Workflow) [50, 107] dealt with the problem of formalization of aesthetic properties of free form shapes by using feature-like concepts as they are known from Mechanical Engineering, with the goal of improving the way CAD tools are used as a mean of communication and collaboration between mechanical engineers and style designers.

4.1 Discussion

Although these results give a very thoughtful account of many important aspects of the subject, it is clear that a comprehensive model for the representation of aesthetic knowledge is still missing.

Studies in psychology and perception have produced a wealth of results related with the quantitative analysis of many basic aesthetic properties and qualities, such as proportion between measures, color, and so on. However, the hypothesis, that seemed so appealing in the first half of the 20th century, that these result could quickly scale up to a quantitative normative theory of beauty, capable of expressing the aesthetic value of a generic artifact as a point in a low-dimensional (or even mono-dimensional) continue space, appears today as irremediably naive. The fallacy of this approach comes from the fact that the factors (both perceptual and cultural) that influence aesthetic judgements are diverse and intrinsically irreducible, and at the same time complexly interweaved; furthermore, many artifacts are, by their own nature, aesthetically maintained as 'inestimable', and that makes a quantitative comparison approach foundationally inadequate. Thus, the utility elicitation approach commonly used in multiple criteria Decision Theory is fundamentally lossy when applied in this domain: in my view, aesthetic judgements are not evaluated, but rather *explained*, by means of a structured symbolic (i.e. linguistic) entity.

Being an intrinsically multi-disciplinary and very complex theme, it is not convenient nor feasible to try to build a model from scratch: my approach is to start from already consolidated theoretical foundations on this subject from Philosophy, Art Theory, Psychology and Semiotics, choosing the approaches that appear to be best suited to be translated to a formal model. Once a formal model has been devised, it will be implemented and tested, and its computational properties will be studied.

Also, I'm only interested in representation and automated processing of *human generated* aesthetic knowledge, in order to support human-centered design activity; I am *not* interested in trying to devise algorithms that automatically extract aesthetic knowledge from the artifact, or that automatically create aesthetic artifacts, being this a goal that appear unrealistic, given the current state of the art of AI and Knowledge Representation research. In other words, I want to devise a *descriptive* computational theory of aesthetics, rather than a *normative* one, being the latter a much more long-term effort.

5 Further work

There are several ways in which this research can be taken further, that I will not pursue in the time frame of my doctorate, but are anyway worth mentioning.

First of all, artifacts classified as expression of a given aesthetic style are considered such only by public judgement, and that implies that sociological aspects must be taken into account [136]. Each human being (or, more generally, each autonomous agent) has its own aesthetic tastes, deriving from both its genetic and cultural background. Each community, intended as a whole, has its own tastes too (derived from the 'culture' collectively expressed by its members), and these criteria of judgement both influence and are influenced by each member of the community. Moreover, it is often the case that aesthetic preferences in fact *define* the community itself, or play a fundamental role in shaping its identity.

Pierre Bourdieu's Theory of Distinction [20] is the first deep attempt to devise a sociological theory of the conceptual category of aesthetics. Bourdieu introduces the notion of *elite*, whose members influence the taste choices of the mass individuals, by means of the very act of expressing an aesthetic judgement, both explicitly (verbally) and implicitly (by choosing artifacts, like clothing and furniture, for themselves and publicly using and displaying them). Also, the members of the elite retains the power to label mass individuals with judgements of "good taste", which is definitely a socially desirable attribute.

The study of the dynamics of social evolution and transformation of the tastes of both individuals and communities, as well as future trend forecasting, is fundamental for many economical disciplines like Marketing Analysis.

Thus, it would be useful to provide models that take into consideration the following themes:

- the evolution and the mutual contamination of styles and both individual and collective tastes;
- competing communities and individuals that interact and influence each other's tastes;

Furthermore, I believe that the formalization of Semiotics into a computational framework could be an interesting theme of research, since I think that Semiotics, as used in literary studies and visual media analysis, could provide some insight concerning the semantics of the kind of attributes of artifacts that relies on the complex cultural background of an human subject for their interpretation, by providing a model of meaning-making based of the analysis of the 'flow' of meaning attribution in the interconnected complex of perceptual and conceptual signs. A success in this effort could have a significant positive impact in other fields, such as natural language understanding or common-sense reasoning.

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