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## **Methodological issues in the study of the depiction of cast shadows**

*A case study in the relationships between art and cognition*

Roberto Casati

*Summary.* The relationships between art and cognition constitute a very wide set of largely unexplored and at times undefined or much too speculative problems. The field is narrowed down by imposing some constraints. It is proposed that the depiction of cast shadows, in its early history, could provide an ideal case study which conforms to the constraints. This paper addresses some methodological problems of the study of this case. A sample of relevant Renaissance images is discussed. A typology of depicted cast shadows is proposed upon which further empirical research could be built.

### 1. Shadows in paintings: the problem

Shadows in paintings are an interesting, almost ideal case study for investigating the relationships between artistic practices and cognition. The choice of this subject matter conforms to a very general methodological strategy: look for very *specific problems* in art *production* where the *actual workings* of perception, thought and other cognitive processes not only play a major role but are also *apparent*. The strategy is expected to allow the discovery of potentially fruitful interfaces between artistic work and cognition; in turn, to provide a set of searchable questions for cognitive science, and to redefine some of the methodologies used in studying art.

As a matter of fact, the study of the relationships between art and cognition constitutes a very wide set of largely unexplored and at times undefined problems. It would be advisable to narrow down the field by imposing some constraints. These include, however not exclusively: choosing production or the production-perception interface (vs. purely perceptual approaches); widening the field of artistic products to include demotic art (vs. one-sided focus on beaux arts); selecting a large sample of artworks, possibly exhibiting trial and error endeavours devoted to the solution of specific problems (vs. direct analysis of anecdotal cases that are likely to be biased by poor data selection); requiring the involvement of sufficiently articulated cognitive capabilities (vs. relatively “simple” cognition, e.g. colour cognition) but at the same time choosing capabilities that are sufficiently delineated (vs. large or diffuse capabilities, such as reading words or understanding narratives); and, finally, choosing a field that is backed by substantial empirical research on the cognitive side (vs. general speculations, e.g. on the social role of some artefact building techniques).

The depiction of cast shadows falls pretty well within the methodological limitations listed above. The depiction of shadows constitutes a relatively circumscribed problem with rich developments. It is definitely a smaller topic than the “large” or “oversize” issues in the relationship between art and cognition (artistic pleasure, art and the emotions, perception of representational artefacts, the use of symbols in art, the assessment of artistic value, the use of the body as a model for understanding artworks, to mention but a few). Large or oversize

issues ramify too much and too quickly beyond control to cover the whole of cognition, including social practices.<sup>1</sup> At the same time, shadow depiction is a sufficiently articulated artistic practice.<sup>2</sup> It involves cognitive capabilities that are definitely larger than “small” or “microscopic” issues such as colour perception or of the detection of symmetry. Moreover, shadow depiction lies right halfway between production and perception. It is close to the production-perception interface insofar as painters learned to depict shadows and appeared to be sensitive to the aspect shadows have and ought to have. In order to depict shadows the painter must master optical and geometric facts and principles, and must put this mastery to the service of a perceptually plausible representation. These efforts are documented in a vast (so far largely unexplored) corpus that may provide sufficient statistical support to empirical hypotheses, provided one can operationalize the relevant variables. Finally, there is a large body of research devoted to shadow perception and cognition where it is possible to mine data that constitute a benchmark for evaluating actual pictorial practices. I turn now to some aspects of this research.

## 2. Fundamentals of shadow perception

Both shadow perception, and the contribution of shadow perception to the perception of space and objects, are relatively well studied performances of the visual system, although they are not completely understood. Research moved from one simple and elegant idea in computer vision, the recovery of shape-from-shading and relational-structure-from-shadows: in principle, it is assumed that shadows and shading *can* resolve some 3-d ambiguities in a scene typically represented by a 2-d line drawing. The paradigmatic ambiguities resolved by shading are curvature polarity ambiguities. Some visual 2-d structures appear to be indifferent as between a concave or a convex interpretation, until shading is added that can overcome the indifference, if supplemented with suitable information about the location of the light source.<sup>3</sup> The paradigmatic ambiguities resolved by cast shadows are positional indeterminacies. Some visual structures corresponding to objects or surfaces appear to be located at an indeterminate distance from other structures, until their cast shadow is added that may signal the relative position of the two structures. Typically, if an object touches its shadow, then it touches the surface the shadow is cast upon.<sup>4</sup>

These studies capitalized on the mathematics implicit in perspective methods and in methods for drawing shadows developed by artists after 1400, and on the sophisticated reverse optics studied by post-Galileian astronomers in order to recover shape from patterns of shadows and shade on celestial bodies (in particular, the Moon) observed through a telescope in impaired or limited viewing conditions.

In recent years it has become increasingly clearer that the role of shadows in the recovery of 3-d shape and structure, although beyond doubt in many occasions, is somewhat less uncontroversial in others. The *possibility* of recovering shape and position from shadows is not questioned. Rather, it turns out that shape-from-shadow may be dominated, in many a circumstance, by other factors. The most relevant facts are the following. 1. Impossible shading is tolerated, provided we can independently recognize (or have some access to the shape of) the object (Braje, Legge, Kersten 2000). 2. Impossible shadows are not usually

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<sup>1</sup> For an assessment of “large” issues, see Casati 2002.

<sup>2</sup> Artistic practices of comparable “size” and relevance are line drawing (Cavanagh 1999) or empathic or simulational understanding of body postures (Quiviger 2002).

<sup>3</sup> Von Fieandt 1938; Ramachandran 1988.

<sup>4</sup> Kersten, Mamassian and Knill, 1997.

noticed, even when they are flagrant (Mamassian 1999). 3. And in particular, there is the fundamental shadow paradox: in order for shadows to contribute to 3-d interpretation and allegedly to object recognition, they must themselves be recognized as shadows (Casati 2000), a fact that makes shadows less palatable as early and mandatory tools of visual recognition.

Related to the latter problem, an independent line of research (originated by Hering 1878 and Bühler 1922) concerns the perception of cast shadows *as* shadows. It appears *a priori* reasonable that the perceptual system manages to register the presence of shadows, to recognise them as shadows, and to (possibly) discount them. Why? Shadows are transitory marks on a surface, and ought to be distinguished from permanent marks (colour patches, textural features). At the same time, the areas corresponding to shadows are extremely salient in the retinal distribution of luminance; shaded zones are often the darkest zones in the visual environment. Here the task faced by vision is not particularly simple, as the solution to the problem of perceiving and discounting shadows should be both robust and flexible: a powerful “shadow filter” risks intercepting non-shadows (object structures or permanent properties), whereas a weak filter risks letting shadows pass through and compete with objects or else become powerful attractors for attention.

Now, some basic conditions must be met for something to be perceived as a shadow.

1. The luminance of the shaded area must be substantially weaker than that of the surroundings, and the luminance distribution within the area and in the surroundings should follow some regular pattern.<sup>5</sup> A certain “shadow constancy” should be preserved, so that the shadow does not break down into pieces.<sup>6</sup> 2. A shadow terminator (distinguishing the shadow from the lit up area) must be perceived.<sup>7</sup> 3. The terminator should not coincide with a discontinuity on the surface the shadow is cast upon (be it a line, or a difference in surface texture), as apparently the visual system bets on two reinforcing marks’ being an implausible coincidence, and discards the shadow interpretation. (This is tantamount to a generic viewpoint assumption for visual perception, where the viewpoint has been conceptually replaced with the position of the light source.)

It also appears that the mechanisms for shadow perception are present in very early perceptual processing.<sup>8</sup> Experiments performed within the so-called “rapid search paradigm” have shown that in early perceptual processing discounting of shadows can be very effectively performed and that it exploits the (1)-(3) features of shadows. (This constitutes a possible resolution of the fundamental shadow paradox.)

### *Shadow Depiction*

What we know of both perception through shadow and of shadow recognition is relevant for making some basic claims about the depiction of cast shadows. If the depiction of cast shadows is to contribute to the main visual purpose of a representational painting – enhancing the shape and location properties of the depicted objects – then shadow depictions should conform to the visual strictures on the perception of real shadows. If for shadows to play a

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<sup>5</sup> Illustrated by the Adelson checker shadow phenomenon.

<sup>6</sup> The shadow constancy phenomenon needs investigating. I surmise it is related to the conditions for the perception of transparency.

<sup>7</sup> Kennedy 1974.

<sup>8</sup> Ron Rensink, communication at the Shadow Workshop, European Society for Philosophy and Psychology, 2001.

role they must be recognised as shadows, then their depiction should make it plain that they figure as shadows in the painting. Finally, if the contribution of shadows to recognition is not straightforward and has hidden complexities, then discovering such a contribution would have taken some effort by painters and cognitive psychologists alike.

On the very last point cognitive science meets art history. On the art historical side, three facts are worth mentioning. 1. Attached shadow (chiaroscuro) is not universally used in depiction, but even whenever it is mastered skilfully, it is not generally accompanied by the use, let alone the mastering, of cast shadows – cast shadows are rare until the European Renaissance.<sup>9</sup> 2. After the Renaissance, shadows in European painting were canonised and shadow painting was the subject matter of a number of painting treatises.<sup>10</sup> 3. But above all, during a circumscribed period in history, the depiction of cast shadows has been the object of a representational struggle. Painters of the early Renaissance appear to have been fascinated by shadows, and to have learnt over about one century how to depict them in a geometrically and perceptually adequate or satisfactory way (the import of these normative notions needs, of course, a discussion). Cast shadows appear to have entered painting on specific occasions related to the content of the painting. These contingencies include the fact that the represented narrative involves a shadow<sup>11</sup>, or possibly the curiosity of some painter who found a cast shadow particularly attractive. Cultural factors and common-sense theories of light may have played a role in these early attempts. According to Toyama 1997 early anecdotal representations of complete and well defined cast shadows require that light source be visible in the painting.<sup>12</sup> According to Stoichita 1997, early depiction of shadows for ordinary objects was set in explicit opposition to the absence of shadows for supernatural entities.<sup>13</sup>

These facts are interesting. If shadow painting were universally widespread, or the automatic by-product of some universal painting techniques, it would require a very general level of explanation. If, on the other hand, it were a completely random factor, it would not be interesting for the study of the relationships between art and cognition. Now, we do appear to find in the development of Renaissance painting a certain systematic pattern of types of shadow depiction. It also appears that some form of learning has taken place: the painter's community struggled with cast shadows until some satisfactory means of depiction were established and then propagated.

In sum, shadow representation is an ideal case for the study of the art-cognition link. There appear to be mechanisms dedicated to shadow processing and recognition. Shadows are accessed by consciousness and attention in interestingly different ways. Shadows can contribute to some aspects of the 3-d interpretation of a scene, and to recognition of the objects in the scene. There is a certain tolerance towards the perception of incorrect or impossible shadows. In order to figure adequately in a pictorial representation, shadows must be recognisable as such. Shadow depiction has been an important challenge for painters, and

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<sup>9</sup> Roman frescoes (such as the ones at Roman Villa of Augustus, 1<sup>st</sup> century AD) and mosaics (such as the ones at Villa del Casale, Piazza Armerina, Sicily, 4<sup>th</sup> century A.D.) have survived that show interesting, if contrived, shadows.

<sup>10</sup> Shadow painting is the subject of some monographs, among which Baxandall 1995 (still linked to computer vision studies), Stoichita 1997 (particularly interested in the symbolic uses of represented shadows), and, briefly but interestingly, Gombrich 1995.

<sup>11</sup> Masaccio (1401-1428), Cappella Brancacci, Florence, *St. Peter healing with his shadow*, ca. 1427. Artworks are mentioned in this study to provide an illustration of the categories discussed by the text. In no way they should be considered as paradigmatic.

<sup>12</sup> Chief examples are *The flight into Egypt* (1436) by Giovanni di Paolo (c. 1403-1483), Siena, Pinacoteca, and *The Stigmatisation of St. Francis* (c. 1437-1444) by Sassetta (1394-1450), London, National Gallery.

<sup>13</sup> Commenting on Giovanni di Paolo *Flight into Egypt*, thereby giving a different interpretation than the one by Toyama quoted in the previous footnote.

there is a vast corpus of paintings, in a sufficiently well-circumscribed historical period and geographic area, that testifies to this large endeavour. This point, however, requires a closer look.

### 3. Renaissance shadow depiction

The methodology of cognitive science is and the methodology of art history are not immediately compatible. In order to present the historical facts of depiction at a level of detail that could be of any use to cognitive scientists, it would be necessary to provide a first qualitative and quantitative assessment of shadow depiction in the period chosen. To that effect, I sampled a number of images that appear to be relevant from Early Renaissance. Where are we heading to? In an ideally completed study, we would look for answers to questions such as the following. Can we provide a control population, e.g. of paintings with no shadows where shadows are expected? What proportion of paintings make use of shadow depiction over the general population of paintings in which shadows may be expected? What proportion of paintings display shadows that are either geometrically adequate, or that respect the distribution of light in the environment, or both? Can we distinguish types of shadow that constitute statistically significant deviations from the norm so as to lead us to detect a systematic pattern of error that could be cognitively relevant? Can we measure variance within the sample? How much of variance is explained as a by-product of some factors correlated with shadows, such as the fact that shadow-casters tend to recur? Answering these questions would be tantamount to possessing a good methodology for quantitative assessments of the content of artworks – a highly debatable and non-consensual issue. In this respect, I shall now discuss two of the main methodological points. First, the question of the size and contents of the sample. Second, problems about the categorisation of the sample.

#### **Size and contents of the sample**

##### *Contents of the sample*

The sample so far includes about one thousand paintings and frescoes inspected at various locations, mostly in Western art museums and collections in Europe and North America<sup>14</sup>. All items registered have been inspected *de visu*<sup>15</sup>, as most available photographs do not convey

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<sup>14</sup> Arizona Museum of Art, Tucson; Ermitage, St. Petersburg; Galleria degli Uffizi, Florence; Galleria dell'Accademia, Florence; Galleria dell'Ambrosiana, Milan; Galleria Nazionale dell'Umbria, Perugia; Galleria Nazionale delle Marche, Urbino; Galleria Palatina, Florence; Galleria Sabauda, Turin; Gallerie dell'Accademia, Venice; Gemäldegalerie, Dresten; Getty Collection, Los Angeles; Metropolitan Museum, New York; Museo Abatellis, Palermo; Museo di Castelvecchio, Verona; National Gallery, Washington; Philadelphia Museum of Art, Philadelphia; Pinacoteca, Siena; Pinacoteca di Brera, Milan; The Frick Collection, New York; Tinker Museum, San Diego.

<sup>15</sup> Paintings are represented in the database by sketches and descriptive (linguistic) categories. The choice of sketches is dictated by (1) the intrinsic difficulty – a near-impossibility – of obtaining good photographic reproduction for painted shadows, (2) the choice to schematize the represented phenomena (following a tradition whose main representative is Arnheim 1974). The main purpose of the sketches, however, is only to pinpoint a location in the painting that is worth studying. Hence accurate descriptions are crucial to the establishment of the database. The sketches themselves should not be used for studying the phenomena. They provide convenient analog categories. But one should be wary of the fact that they constitute a representational medium themselves, and this could induce new categories that may turn out to be artefacts of the theory.

The epistemology of painting analysis and description would require a study in itself. What is the role of observation and attention in studying paintings? Observation is a slow process. How much of it builds upon

enough relevant detail (especially in terms of lightness contrast, and of size of the relevant portions of the image).

#### *Spatial and temporal boundaries of the population*

Paintings included were produced in Italy the Netherlands and Germany over a century in the interval 1415-1515. The period has been circumscribed for historical and statistical reasons.

1. The few documented earlier cases of shadow depiction (in Roman and Hellenistic painting) are either sporadic, or they do not permit the establishment of a sufficiently large sample. 2. There was a sustained interest in shadow depiction in early Renaissance that gave rise to a large number of “pictorial experiments”. In those “experiments” shadows are depicted to varying degrees of success. 3. After the Renaissance, shadow theories developed that solved a number of practical problems for painters by proposing algorithms, and either rendered shadow depiction routine (to some extent), or else made it plain that painters acknowledged the existence of an issue about depicting shadows. That is, painters were aware of the fact that there was a specific problem of shadow representation and a canon of techniques that addressed the problem.

Some paintings have been inserted from periods other than Renaissance, for their historical or intrinsic interest, or to provide a contrast class.

It is estimated<sup>16</sup> that a population of about one hundred thousands Italian Renaissance artworks have survived; possibly half as many from the Netherlands. This would put the sample at less than 1% of the total. The statistical significance of the sample is at this stage hard to assess, given that the paintings studied are those from major collections, whose choice of paintings to display are likely to bias the sample towards important historical characters (and away from ‘demotic’ art). However, the sample’s large size may allow for correction of some biases.

*Ratio of paintings with shadows.* In general, all paintings which have been found to represent a shadow have been inserted. Not all paintings from the concerned period have shadows, and the present research does not take into account the ratio of paintings with shadows to the overall population. Only paintings with shadows have been inserted in the sample. Moreover, not all shadows are “interesting” (at times, there is just a hint of a shadow), and the corresponding paintings have been discarded.

*Homogeneity.* Given the nature of the sample and of the feature under study (presence of cast shadows), it is hard to provide a measure of the homogeneity of the sample. Paintings are of various sizes, made with different techniques, etc. However, a certain amount of homogeneity is imposed on the sample by the fact that item is a *representational* painting, and by the particular topic under investigation: when it comes to shadows, contingencies are robust. Typically, it is opaque objects that cast shadows; persons are among those objects. Rare are the cases of semi-transparent objects casting shadows. In addition, subjects tend to recur. For instance, when the human figure is depicted, feet are where shadows usually originate.

#### *Other limitations.*

Some limitations of the sample are likely to affect the results of the research in other ways. There is no study of the *techniques* involved in paintings: oil, watercolour, fresco, etc. These may differentially influence production and the perceptual outcome in significant ways. The sample does not discriminate at this point between different techniques, but it appears to be

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quick perceptual processing? Some of the remarks in this essay are akin to those of a painter who is learning shadow effects by looking at other painters’ work. Is there more than an analogy here?

<sup>16</sup> Paul Taylor, personal communication.

possible to retrieve the relevant information in the future. More generally, there is only a limited study of the *means* involved in depicting *shadows*. These can be as varied as to include “altering” the colour of the shadow zone by painting it over,<sup>17</sup> covering it with tiny brushstrokes, or creating an autonomous patch of a different colour. There is no study of *sinopiae* or of preliminary drawings for the paintings. An independent study should be done on drawings (as the medium largely affects what can be represented and the rendering of shadows<sup>18</sup>). An independent study should be done on the discrepancies between preliminary studies and the final paintings. It is also arguably difficult to distinguish between original shadows and shadows added during restoration. It would be interesting to test whether post-Renaissance copies of Renaissance paintings add or otherwise “correct” or “improve” shadows.<sup>19</sup>

These all too evident shortcomings make the sample inadequate so far for any strict inferential statistics purposes. However, the expected large number of sampled items in the final database should allow for some corrections, and variance within the sample may show interesting tendencies in the depiction of cast shadows. Moreover, it is hoped that lessons can be learned by the study of this pilot examination that will make a broader study possible: in particular, the terminology used for describing complex visual categories could be stabilised. This brings us to issues of categorisation.

## Categorisation

A second, equally important set of problems concerns categorisation. How do we tag the contents of paintings? What categories can be taken as representative, that could be *both* true to historical facts and the intention of the painter, *and* cognitively interesting? The three main aspects of the problem are (i) the role of object-driven categories in describing paintings’ content, (ii) the role of normativity in classifying shadows, and (iii) the potentially artificial nature of the categories invoked.

(i) *Object and property categories and the sub-iconographic level.* On top of the obvious biographical and historical categories, the purpose of the present study is to individuate potentially interesting *visual categories*, that is, ways of organizing the sample according to perceptual features that could be relevant for a cognitive scientist. *Prima facie* this is done at the level of description that Panofsky (1939) termed “pre-iconographic”: the identification of the *types* of objects (tables, people) and events (battles, gestures) depicted, on the basis of the viewer’s everyday (visually related) beliefs about objects and events of the corresponding types. However, this level is not deep enough, as some visual phenomena of interest to cognitive scientist could simply not be consciously “given” to the viewer or the artist, and could nevertheless leave a trace on the painting. The viewer may simply be unable to notice that two shadows point in inconsistent directions, whereas at the pre-iconographic level a non-impaired viewer is always assumed to be able to describe a painting. To coin a neologism, we could speak here of a “sub-iconographic” level of description of a paintings’ content.

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<sup>17</sup> For an example of a clearly overpainted shadow, see Master of the Tiburtine Sybil (active 1470-1490), *The Marriage of the Virgin* (1480), Philadelphia Museum of Arts.

<sup>18</sup> In the *tarsie* (woodcut) in the Studiolo at Urbino (second half of the 15<sup>th</sup> century) shadows are represented by actual pieces of wood. The sfumato (softening) is represented with small wood insets.

<sup>19</sup> Perugino (1445-1523), *Vision of St. Bernard* (c. 1491-94), Munich, Alte Pinakothek, as copied by Felice Ficherelli, Florence, Church of St. Spirit (1655-1656); apparently the copy does not improve on the original.



When dealing with broad classificatory categories, we should take into account the role *objects* play in classifying shadows. Certain objects recur in paintings as privileged shadow casters. Some other objects may recur as privileged screens on which shadows are cast. In the data structure there ought to be an item for *shadow of steps* and one for *shadow on steps*.<sup>20</sup>

As it is assumed from the onset that recognitional capabilities are activated when observing a painting, some general conundrums enter stage, related to the classification of image contents, which are not specific of shadows. First, it appears that in some cases the iconographic level determines the pre-iconographic level. Panofsky himself in his (1939) gave an example of the impossibility of specifying the pre-iconographic level on the basis of the everyday beliefs of the viewer. A certain representation in a painting by Roger van der Weyden was determined by the art historian to be a ghostly appearance of the Child, but there is no way of giving a proper description of that aspect of the painting's content at the pre-iconographic level, in everyday experience terms (a floating baby?). Second, even in more mundane cases, the pre-iconographic level may be simply underdetermined beyond resolution. Wittgenstein (1953, §139) made this plain with the example of the image of a man who is climbing up a hill: it could as well be the image of a man who is gently sliding back downhill. Even more generally, the whole problem of inverse optics is based on the assumption that the 2-d image cannot completely specify the 3-d interpretation. Third, and more specifically, the labelling of shadows in paintings is subject to top-down influences or general knowledge about factors that do not translate into visual features, hence is not immediately readable off an inspection of the painting. For instance, painted shadows may be indistinguishable from painted cracks, and some contextual elements may be necessary to disambiguate the corresponding configurations. Another example of a factor which does not show up as a feature is the default assumption about the direction of light. Yet another is the assumption of the uniqueness of light source, which could only be made explicit after some discursive analysis of the painting. Fourth, a problem arises with the notion of type-identity of objects, as in judgements to the effect that "the same objects appear in different paintings"<sup>21</sup>. We may be interested in speaking of the same object type (say, *protruding foot*), of the same geometric body (say, *cylinder on cube* or *geon of type F*<sup>22</sup>). These problems are likely to affect the criteria for structuring the data: *shadow of protruding foot* is included in *shadow of protruding object*, but should it be included in *shadow of protruding geon of type F*? Somewhat, a type-identity across images must be assumed in order for comparisons to be made. A way around this problem is related to an important distinction between paronomies and categories (Tversky 1990). Parts of objects tend to be classified in a cross-categorical way, that depending mostly upon shapes and functions. Thus, objects of very different types have handles or arms. Finally, a database of pictorial contents need not be biased towards objects and properties. It may as well contain event-type or fact-type description: an event-based description may be contrasted with a geometry/geon descriptions, and the relation between the two may require

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<sup>20</sup> The idea is to have a keyword that is part of the categories ('step') that does not license an inferential relation between the two items.

<sup>21</sup> As we only talk of here object types, this is not an instance of the type/token ambiguity.

<sup>22</sup> In the psychological literature, the notion of a *geon* (geometric ion: Biederman 1985) has been used for classifying solid shapes at a level compatible with that of object recognition and with that of elemental perceptual processing. Geon-representations are more structured than the representations of solid bodies in descriptive geometry, can be generated in a recursive fashion, and behave compositionally. Geon analysis could be another promising area for interfacing artistic practices and cognition; as a matter of fact, many drawing textbooks present a technique of figure building that has analogies with (and perhaps inspired) geon-based theories.

an examination. After all, shadows are dynamically cast by an object; shadow casting is an intrinsically causal notion.<sup>23</sup>

In spite of all these reservations, a sufficiently fine-grained level of object description seems to be available that makes it possible for a categorisation of shadows to satisfy two requirements: possibility of comparison across paintings, and establishment of categories comprising a significant number of individuals.

(ii) *Normativity*. As I mentioned above, I am making a substantial use of the notion of “mistake”. There is a normative gist that guides part of this research. Some painters are here said to have made *errors* in depicting shadows. Of course this is in no way an aesthetic or strong evaluative appreciation: the notion of mistake is used here only methodologically, as representational mistakes are the essence of psychological research. Moreover, mistakes are interesting insofar as they are found to be systematic. There are clear cut examples of area in which an error is likely to occur, such as the geometry of shadows, or the luminance of shadow zones: here paintings may simply not conform to normative shadow appearance as specified by optics and psychology of perception. There are less clear cut cases in which shadows appear strange but may just be possible – in such cases care must be put into ascertaining whether a depicted shadow has an ecological counterpart that may simply have been overlooked. For instance, converging shadows may actually occur in nature<sup>24</sup>; pointed shadows of columns or people’s legs do exist in reality when the sky is covered (light comes from an extended surface); triangle or spike shadows (small triangular spikes that emanate from the bases of objects) may appear surprising in a painting, but they may be perfectly acceptable ecologically – only, they would not, in the norm, be noticed. Painters may have registered reality in a way that normally escapes our attention. This suggests that we should be guarded against ‘observer mistakes’, as in classifying a painting we may be under the illusion of knowing that a certain shadow is correct or incorrect.<sup>25</sup>

(iii) *Whose category?* Finally, we should ask ourselves *whose* concept, whose category is the one used for the classification. Suppose we have reasons to employ a concept of *shadow climbing steps* in describing a painting. Is this a concept possession of which we should attribute to the painter or is it a figment of our own theory? Historical research may be of help here, by uncovering written documents that use or define concepts akin to those listed in the database. However, it may also be the case that painters have discovered categories for which a name was not available or which had a different meaning. A certain amount of trade-off is expected here.

#### 4. The database structure: Shadow categories

The following is a first attempt at listing the categories that are likely to play a prominent role in the database. The list is based on an informal examination of the pilot sample and is, at this

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<sup>23</sup> Masaccio, *St. Peter heals with his shadow*, Cappella Brancacci, Florence (1427). See Talmy 1997 on the dynamic structure of shadows.

<sup>24</sup> Signorelli (c. 1450-1523), *Flagellation*, Milan, Brera (c. 1480).

<sup>25</sup> On a more technological side, it may be worthwhile investigating the *correct* shadows as to have a normative baseline and controls for evaluating a shadow in a painting. I can think of two methodologies here, both of which use digital means. (1) Reconstruction. In order to obtain the correct depiction of a shadow in a given context we may reconstruct the 3-d setting and use a CAD system to cast the expected shadow. (2) Cancelling. To enhance the understanding of the role of a given shadow representation, it may be worth cancelling the shadow by digital means.

point of the research, still open-ended and in need of various checks. A few macro-categories, subsuming finer-grained categories, are hinted at in what follows.

If we are to establish a baseline and control groups, we should start from *shadowless paintings*. These images are useful for showing the slightly awkward visual appearance of objects and spaces when shadows are absent. Objects may appear to float above the ground. The paintings are not devoid of 3-d structure, but arguably this is weaker than the structure obtained with full-blown shadows. It is interesting to investigate a number of shadowless paintings in order to show the non-obvious presence of shadows in paintings.

When we look at the main features of the sample, we find a rough primary and overarching macro-categorisation distinguishing between *mainly imitation shadows* vs. *mainly instrumental shadows*. Instrumental shadows are items used to specify the position and the spatial structure of objects. In an imitation shadow we can easily recognise the shape of the shadow caster.<sup>26</sup> Imitation shadows result from attempts at drawing anecdotal shadows, typically with a narrative function. The two categories are obviously intertwined: by imitating an object's shape, an imitation shadow would be instrumental in showing that shape. Still, this would not be a straightforward instrumental case, as it would not rely on shape-from-shading mechanisms. Moreover, an imitation shadow can perform other functions, such as signalling the portion of an object relative to a surface.

A *virtuoso shadow* is typically a cast shadow that either is an imitation shadow (the shape of the object is perfectly recognizable) or follows very closely the shape of the object it is cast upon (although the object may not be recognisable by looking at the shadow).<sup>27</sup>

The depiction of a virtuoso shadow seems to presuppose that the artist has devoted some attention to the study of real-life shadows; however, the shadow may also have been computed, not observed, by the artist.<sup>28</sup> In either case, the presence of virtuoso shadows indicates an interest in depicting shadows for their own sake; shadows appear to have been painted *on purpose*, possibly to attract the attention of the viewer.<sup>29</sup>

In between purely instrumental and imitation shadows figure *triangle or spike shadows*<sup>30</sup>. It is as if once the anchoring function was secured, the artist started experimenting with the geometry of the shadow, until he found a sufficiently convincing shape. Curiously enough, an ancient experiment along similar lines produced a less satisfactory, but interesting result,

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<sup>26</sup> Vittore Crivelli (c. 1450-1500); S. Giacomo della Marca; Urbino: the shadow of the key perfectly imitates the key. Daniele Ricciarelli (c. 1509-1566), San Giovanni Battista Decollato, Turin, Galleria Sabauda (c. 1550), with an interesting, somewhat surprising imitation shadow of hand.

<sup>27</sup> Bottega del 1473, *San Bernardino appare di notte*, Galleria Nazionale dell'Umbria, Perugia.

<sup>28</sup> In a very early (end of 14<sup>th</sup> century) miniature by Belbello da Pavia (active 1430-1473) in the Visconti Hours (Florence, Biblioteca Nazionale) as described by Kirsch 1972, "extremely bold is the elaborate shadow cast on the wall at the left by the figures, their rope and plank, and even one of the staffs, whose shadow continues over the blue base of the wall onto the grass"(LF 131 v.). Here the profile of the shadow matches the profile of the figures as we see them, and not as a light source could see them – hence the shadow has been computed, not copied. (I am grateful to Fabrice Teroni for this reference.)

<sup>29</sup> Carlo Crivelli (c. 1430-c. 1492), *Madonna della Candeletta* (1490-1491), Milan, Brera. The candle, strangely suspended in mid-air, or glued to the step, is a strong eye-catching element. There are other virtuoso shadows in the image, but this one seems to be made for triggering a narration. Virtuoso shadows can be conceived of as strong prompts for conversation. Explicit prompts for conversation are not unfamiliar in Renaissance art (on artworks in general as conversational prompts see Casati 2002). The topos of the trompe-l'oeil fly falls in this general category. It is interesting to compare another painting by Crivelli, *Virgin with Child*, New York, Metropolitan (c. 1480), where the fly's shape and size are inconsistent with the fly being part of the scene, whereas the shadow is inconsistent with the fly *not* being part of the scene.

<sup>30</sup> Gerolamo da Treviso il Vecchio (1451-1497), *Cristo Morto Sostenuto da Due Angeli*, Milan, Brera.

*reverse triangle shadows*, where the shadow diverges as it moves away from the caster, and is then abruptly truncated<sup>31</sup>.

When we move to instrumental (position-determining) shadows, we have first and foremost a number of items in the category of *anchoring shadows*, that signal the relative position of object and surface. The ecological contingency exploited here is that an object touches its shadow whenever it touches the surface the shadow is cast upon. Absence of object-shadow contact is an index that the object does not touch the surface. Anchoring shadows are ubiquitous. Very widespread within the category is the theme of the *shadow of a stick touching ground*<sup>32</sup> – and absent is the shadow of a stick *not touching ground*; in general, shadow of suspended objects are rare.

A spurious but utterly interesting category is that of *marks with no shadow feature but with an unintended shadow function*. They are not shadows but are unwillingly used by the visual system to locate objects on the ground.<sup>33</sup>

A macro-category is that of *surface enhancing shadows*. This type of shadow informs the viewer about the structure of the surface it is cast upon. Very much represented within the category is the shadow of a *horizontal object partly suspended over the ground and touching it in two points*; typically a bone at the basis of the Cross, or a sword lying on a stone, whose shadow suggests surface slant.<sup>34</sup> Also popular is the *shadow that climbs a step* (or an *obstacle*, more generally; but in many cases a step or series of steps).<sup>35</sup> Finally, the *shadow of a protruding object* (typically a foot jutting out of a pedestal, or a knife out of a table) signalling a step and the fact that the object is jutting out.<sup>36</sup> (Other typical protruding objects are sticks and mantles.<sup>37</sup>) This type of shadow exemplifies the problems posed to categorisation by the fact that shadows are cast by objects, and are hence conceptually parasitic upon them. In some cases it would seem essential to list a shadow category not only by the shape and the function of a shadow, but also by its typical shadow caster.

Not only surfaces can be enhanced by shadows. There also are *object-enhancing shadows*. They usually are not very compelling as shadows, but are useful to enhance the body against the background.<sup>38</sup>

Cognitively interesting categories comprise a series of *variously mistaken or inappropriate shadows*. These include *truncated (incomplete) shadows*<sup>39</sup>; *shadows truncated at edges*, typically *shadows that do not climb a step*, stop at a surface discontinuity; *shadows that climb*

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<sup>31</sup> These are mainly documented in Roman mosaics (Smirat, Tunisia, 3<sup>rd</sup> century A.D., and Piazza Armerina, Sicily, 4<sup>th</sup> century A.D.) and have an echo in the mosaics of Ravenna, Mausoleo di Galla Placidia (425-450 A.D.).

<sup>32</sup> Bartolomeo Vivarini (1432-1499), Polittico di Conversano, Venice, Accademia (1475). In two different panels the stick possesses and lacks a shadow, respectively.

<sup>33</sup> Anonymous, *Triumph of Love*, Museo Bandini, Fiesole (second half of 15<sup>th</sup> century).

<sup>34</sup> R. van der Weiden (c. 1400-1464), *The Crucifixion* (c. 1460), Philadelphia.

<sup>35</sup> Vittore Carpaccio (1473-1526), *Presentazione della Vergine al Tempio*, Brera, Milan.

<sup>36</sup> Vittore Crivelli, *Pietà* (c. 1481), Urbino, Galleria Nazionale delle Marche.

<sup>37</sup> Giovan Battista Caporali, *Pala di S. Girolamo*, Galleria Nazionale dell'Umbria, Perugia.

<sup>38</sup> Crivelli, *S. Giacomo della Marca*, Urbino, Galleria Nazionale delle Marche, is the only case I am aware of an object that has *both* a neat cast imitating shadow *and* a small enhancing shadow; the two shadows are inconsistent.

<sup>39</sup> Piero della Francesca (1416-1492), *Annonciation*, Galleria Nazionale dell'Umbria Perugia (1460-1470). Although I listed these shadows in the “mistakes” category, they could possibly correspond to an ecologically valid situation.

*a step wrongly*;<sup>40</sup> *film-like shadows*, where a shadow appears as a superposed half-transparent film.<sup>41</sup> There are furthermore cases in which *only one or some* of the potential shadow casters do in fact cast a shadow<sup>42</sup>; cases in which there are *shadows of objects that ought not to cast a shadow*;<sup>43</sup> *inconsistent shadows*;<sup>44</sup> *shadows that bend around a corner*;<sup>45</sup> *crossing shadows*;<sup>46</sup> *shadows that interact poorly with the surface they are cast upon*.<sup>47</sup>

But not only normatively erroneous shadows are important. There are also a number of *shadow exotica*, which, like the virtuoso shadows, indicate the painters' interest – and mixed successes – in depicting complex visual structures. We have here *shadows from multiple sources*<sup>48</sup> (insofar as they do not count as inconsistent shadows); *silent witness shadows*, which testify to the presence of an object which is not visible in the depicted scene;<sup>49</sup> shadows cast *by an object situated on our side of the canvas*; shadows cast *by a light situated on our side of the canvas*. (This category subsumes the previous one for geometric reasons: if an object situated on our side of the canvas casts a shadow inside the painted scene, it is because the source of light itself is on our side of the canvas.)<sup>50</sup> We have, furthermore, *broken shadows* (shadows cast on two disconnected surfaces<sup>51</sup>); *occluded shadows*; *shadows on water*<sup>52</sup>. A number of taboos appear to be widely respected, as is indirectly proven by the striking appearance of the infringements: the *taboo of the shadow on the body*<sup>53</sup>, more generally of the shadow on human or animal figure or part of figure.<sup>54</sup>

<sup>40</sup> Girolamo Genga (1476-1551), *La Madonna col figlio, santi e dottori della chiesa*, Milan, Brera, where the shadow of a singing putto does not bend following the steps.

<sup>41</sup> Domenico di Paride Alfani, *Pala della Sapienza Vecchia*, Galleria Nazionale dell'Umbria, Perugia, where the shadow of the Virgin is much too dark. Note that Arnheim described shadows as having the appearance of transparent films. However, the ecological phenomenology does not seem to support this description: shadows do not appear normally as being *superposed* to surfaces.

<sup>42</sup> Anonymus, *Adoration of the Magi*, San Diego.

<sup>43</sup> Giovanni Santi; Sei Apostoli; Urbino.

<sup>44</sup> Signorelli, *Flagellation*.

<sup>45</sup> Conrad Witz (1400-1446c), *Adoration of the Magi* (1443-1444), Genève, Musée d'art et d'Histoire.

<sup>46</sup> Vivarini (1442/53-1503/05), *Madonna col Bambino e Santi*; Urbino.

<sup>47</sup> Some of these shadows heavily blacken the area they are cast upon. In Gaudenzio Ferrari (1480-1546), *Presentazione di Maria*, Milan, Brera, the shadow from a character inverts the baseline luminosity of steps.

<sup>48</sup> Piero della Francesca (1416-1492), *Flagellation* (c. 1455), Urbino.

<sup>49</sup> Tarsie, *Studiolo*, Urbino, where a glass pane superposed to a column is almost invisible but for the silent witness shadow. In recent art, painters have made a deliberate use of an even more extreme device, that of *orphan shadows with no object to cast them* (not only an object in the painting, but most likely an object tout court). I can think here of Filippo de Pisis (1896-1956), *Natura morta marina con la penna* (1953), Milan, Brera, where a number of shadows have no object casting them. Obviously, in order to categorize them as shadows we take stock of the fact that some objects *do* cast a shadow in the painting and that the latter are quite similar to the orphans.

<sup>50</sup> Giovanni Bellini (1430-1516), *Pietà* (c. 1465), Milan, Brera; the shadow of Christ's left hand indicates a light on our side of the painting.

<sup>51</sup> Domenico Ghirlandaio (1449-1494), *Presentation of the Virgin at the Temple* (1486-1490), Tornabuoni Chapel, S. Maria Novella, Florence; the shadow of a flask is split over two steps.

<sup>52</sup> Biagio D'Antonio (1445-1510), *The Story of Joseph* (1485), Getty Museum, Los Angeles, which also provides an example of the two preceding categories. Vittore Carpaccio, *Hunting on the Lagoon* (1490), Getty Museum, Los Angeles, has many reflections on water, clearly distinct from shadows: even the *reflection of a shadow* is present.

<sup>53</sup> Violated (much later) e.g. by Bernardo Strozzi (1581-1644), *Convito in Casa di Simeone*, Venezia, Accademia.

<sup>54</sup> Violated e.g. by Eustachio di Jacopo di Cristoforo, *Adoration of the Magi*, Galleria Nazionale dell'Umbria Perugia, where the shadow of right foot climbs right foot. This is also an example of a *shadow that climbs a step*.

Finally, I shall mention *unintended shadows*, that is, parts of the representation that were likely meant not to be shadows but that do appear as such. Among these, the category of so called “*crackdows*”, halfway between shadows and cracks.<sup>55</sup>

Categories can *overlap*. We can find items that are both a triangle shadow and a shadow that does not climb a step<sup>56</sup>, or both a triangle shadow and a shadow that climbs a step<sup>57</sup>. Examples of displays in *mixed categories* are interesting because they confirm the conceptual role of the primitive categories.

## 5. Conclusions

Shadows are an important and well studied ingredient of visual cognition. Shadow painting is not universally widespread, and is not the automatic by-product of some painting technique. Hence it is interesting for the study of the relationships between art and cognition. To that effect, the methodologies of cognitive science and that of art history must meet. I proposed to look quantitatively, but with an eye to quantities, at early shadow painting in the Renaissance. A first pilot sample has been examined: general sampling and categorisation issues have been discussed, and a terminology has been proposed that could bridge the gap between categories relevant to the art historian and categories relevant to the cognitive scientist.

From a cursory analysis of the art historical sample we can draw some provisional conclusions, considering the relevance of these findings for cognitive science.

First, we do appear to find in the development of Renaissance painting a certain systematic pattern of types of shadow depiction. The pattern has a development that may be compared to a form of learning: the painter, or his community, struggled with cast shadows until some satisfactory means of depiction were established and could then propagate, getting more and more differentiated and sophisticated. From a period in which only some select objects could cast a shadow, we move to the universal and algorithmically constructed attribution of shadows to all objects.

Second, there is a certain convergence on the type of objects that cast shadows, their pre-eminence in the scene, their location. Important objects cast shadows, and marginal objects don't. Possibly this signals places where attention is primarily directed, to the detriment of other, more marginal places.

Third, shadows are typically object and space enhancers and being subservient fellows they are not given much detailed work. When they get centre stage, they are usually depicted so as to imitate (hence be a recognitional prompt for) the shadow-caster. However, in these cases the painter was under two competing pressures: whenever shadows were bestowed representational autonomy, they risked to underperform as instruments to enhance other, more relevant features of the scene.

Fourth, There is a convergence of types of cast shadows and types of shadow casters. This, together with the recurrence of the types of shadows, is suspicious enough, and is an indication that the propagation of shadow representations followed a simple epidemiology, copying.

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<sup>55</sup> Piero della Francesca, *Annunciation*, Galleria Nazionale dell'Umbria, Perugia. This is a crackdow with no easy disambiguation. Cf. also Benozzo Gozzoli (1420-1497), *Adorazione dei Magi* (1459), Florence, Palazzo Medici-Riccardi.

<sup>56</sup> Girolamo di Benvenuto (1470-1524), *Pietà*, Urbino, Galleria Nazionale delle Marche.

<sup>57</sup> Vittore Carpaccio (1472-1526), *Disputa di S. Stefano* (1514), Milan, Brera.

Fifth, we notice that some types of shadows are more interesting than others, such as imitation shadows, and specifically virtuoso shadows, and indicate the painter's interest in shadows. Sixth, the more interesting cases are those of variously inappropriate shadows. The *tolerance* for mistaken shadows is striking. Having first corrected for observer's mistakes, and considered as outliers those shadows that do appear odd but can be found in nature, a number of unaccounted types of shadows remain. We (and the painter as a viewer of his own work before us) can accept virtuoso shadows that appear realistic as they match the visually available profile of the shadow caster, not the profile the caster offers to the light source. We can accept inconsistencies of various sorts (shadows from multiple sources, shadows from a single source pointing in inconsistent direction, selective presence of only some of the expected shadows) without having the impression of a disruption of the visual scene. Seventh, the typology here adumbrated suggests that a large number of shadowlike perceptual types can be used to do the work usually done by shadows.<sup>58</sup>

On the art historical side, by propounding an investigation of a large sample of images that marginally deal with a very narrow problem, this study contains a potential criticisms of traditional methods of art study, on two accounts. First, how much of the methods used in studying art are relying on the personal appreciation of the student or on anecdotal evidence? The modern methods of the social sciences (large numbers, control populations, narrowing down of the cognitive capabilities under study) should allow for some corrections towards a more objective assessment of the contents and relevance of artworks. Second, in the absence of such quantitative endeavours, which kind of *facts* are *described*, which facts are *explained* in studies on art? Isn't there here, as in many other fields of the social sciences, a problem of a *missing explanandum*?

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A large bibliography on shadow cognition, as well as images of some of the items in the sample, can be found at [www.shadowmill.com](http://www.shadowmill.com).

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<sup>58</sup> As in many other cases, painters make discoveries as *ante litteram* psychologists. In our case, they discovered a number of visual concepts. It must be remarked that paintings are also prompts for telling stories, for developing reasonings, for arguing. Many judgements are related to propositional properties of paintings' content.

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