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*LAST BUT NOT LEAST*

# 17 000 years of depicting the junction of two smooth shapes

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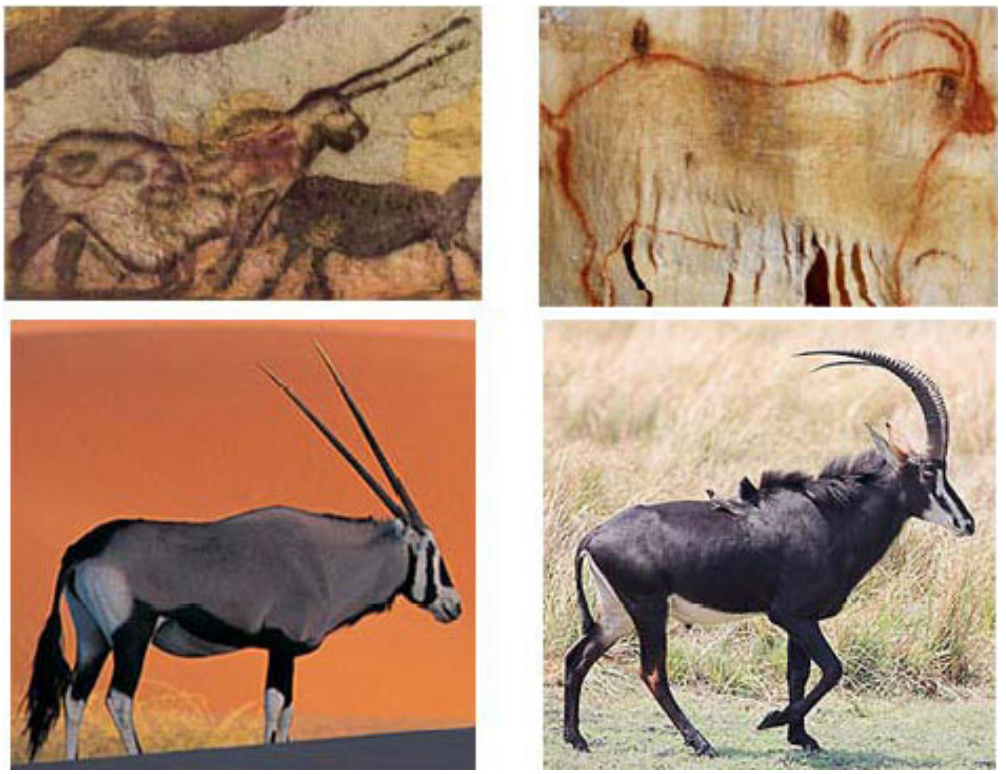
**Abstract.** Competent realistic drawings preserve viewpoint-invariant shape characteristics of simple parts, such that a contour in the object that is straight or curved, for example, is depicted that way in the drawing. A more subtle invariant—a V-shaped singularity of the occluding boundary, containing a T-junction and a contour termination—is produced at the junction between articulated smooth surfaces, as with the leg joining the body of a horse. 45% of the drawings made in 2007 by individuals with only minimal art education correctly depicted such junctions, a proportion that is not reliably different from the incidence (42%) of correct depictions in a large sample of cave art made 17 000 years ago. Whether a person did or did not include the invariant in their drawing, all agreed that it made for a better depiction.

European prehistoric cave art, dating back 17 000 years, has, as its primary subject matter, large mammals such as horses, bison, oryx, sable, rhinoceri, and deer. An examination of these drawings reveals that viewpoint-invariant or 'nonaccidental' properties of simple parts expressed as variations of generalized cylinders (Binford 1971; Biederman 1987), such as whether the axis of the horns are straight (as with the oryx) or curved (as with the sable), as well as the presence of the parts and their relations, are accurately depicted (figure 1). In contrast to the nonaccidental aspects of depiction, informal perusal of the drawings leads to the conclusion that the rendering of metric properties, such as the aspect ratio of a body (figure 1), and the depiction of texture, such as a deer's antlers, are poorly represented. This greater sensitivity to nonaccidental compared with metric differences is evident in the performance of contemporary humans, not only in those immersed in the simple, regular artifacts that are characteristic of the developed world, but also in people of remote tribal areas with minimal exposure to such artifacts (Nederhouser et al 2005). Single-unit recordings of macaque IT cells also provide evidence that there is more sensitivity to nonaccidental than metric property changes (eg Kayaert et al 2003).

In 1982, Jan J Koenderink and Andrea J van Doorn proved that another invariant must be present for articulated smooth surfaces: a V-shaped singularity of the occluding boundary, containing a T-junction and a parabolic contour with a termination (figure 2). Koenderink and van Doorn noted a number of instances where this feature is omitted in otherwise competent drawings. For example, a line drawing of a front view of a breast should be a parabolic open curve, not an oval. The singularity is due to a negatively curved area which serves to bound 'object-like' convex or concave areas (J J Koenderink 2007, personal communication). The transversality-regularity (Hoffman and Richards 1984) performs a similar function in defining a basis of segmenting parts.

As the depiction of animals can be thought of as being largely formed by the join of smooth surfaces, there were plenty of opportunities for our prehistoric brethren to incorporate concave terminators in their portfolio. What was this incidence? And how does it compare with the incidence of this feature in drawings by individuals living today with little or no formal education in depictive art?



(a) (b)

**Figure 1.** [In colour online, see http://dx.doi.org/10.1068/p5907] Examples of horn depictions in cave art. (a) Drawing of an animal with horns with a straight axis (Vialou et al 1992) (above) likely depicting an oryx (below). (b) Drawing of an animal with horns with a backward curved axis (Clottes and Lewis-Williams 1996) (above), likely depicting a sable (below). Often the only species-individuating information is in the shape of simple parts, like the horns in this example.

We assessed this incidence in 215 instances of profile views of animals in which the front or hind legs or both were depicted as joining the body (figure 2a) in collections of photographs (Vialou et al 1992; Clottes and Lewis-Williams 1996; Bahn and Vertut 1997) of cave art in (what is now) France and Spain. Insofar as there was some uncertainty for many of the drawings whether the concave terminator was actually present, we had ten raters judge whether the feature was present, absent, or ambiguous. With 70% or more agreement among the raters, the incidence of the concave terminator was 41.6% (38.7% with at least 60% agreement). These concave contours were all curved in the appropriate direction and, at a first glance, could be approximated as a parabolic arc.

To assess the likelihood of this invariant being depicted in contemporary drawings, 67 subjects were asked to make a realistic drawing of the rear half of a profile view of a horse (figure 2b). Subjects averaged 27.6 years in age, and 53% were female. 44% of the subjects ($n = 29$) reported that they had no art education beyond elementary school; the rest reported an average of 3.5 years of art training.

Only 44.8% of those subjects without formal art training correctly depicted a concave terminator, a nonsignificant difference compared with the 41.6% in cave art (when the art was unambiguous) ($\chi^2_1 < 0.002$, $p > 0.96$). For those with art education ($n = 38$), the incidence increased to 79.0%, a value significantly higher than that for those without such education ($t_{65} = 3.04$, $p < 0.004$). 11 of the subjects were shown

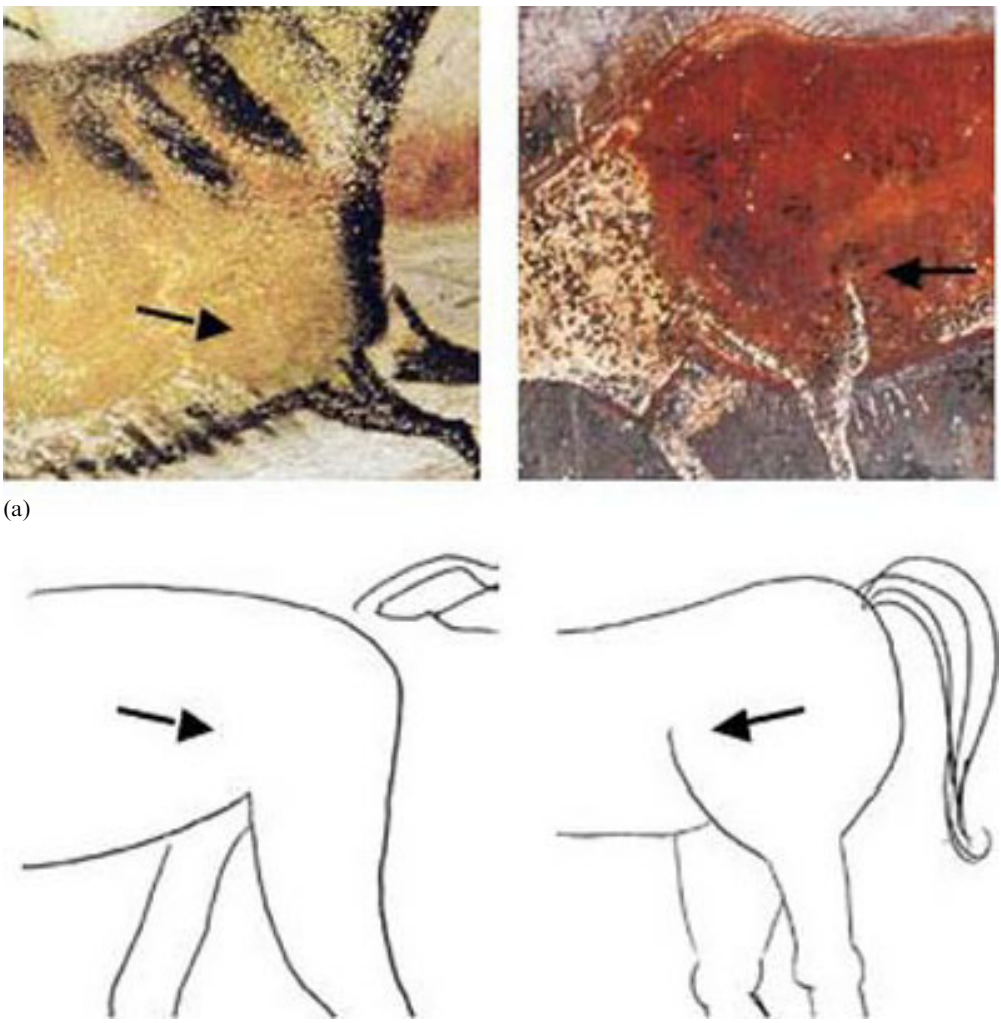


**Figure 2.** [In colour online.] Examples of drawings of the junction between a leg and a body. The T-junction and concave terminator are absent (left) and present (right) in (a) Lascaux art (Vialou et al 1992; Clottes and Lewis-Williams 1996) and (b) contemporary drawings.

two otherwise identical drawings, one with and one without the terminator. All of them, including 7 who had not produced the contour, judged that the terminator made for a better drawing.

We should note that it was unlikely that the prehistoric artists posed a carcass for its depiction and only sometimes had the talent to express the invariance in plain view. The decorated cave walls and ceilings are typically deep inside the caves, at least 60 m in Lascaux, so it is somewhat implausible that the animals, all of which were of considerable size, would have been dragged for such a great distance (rather than, say, eaten fresh). Moreover, with no natural light in these caves, the presence of an animal model would have required additional lighting. The employment of this invariant was thus likely a part of the explicit knowledge of some of these artists.

Whereas the nonaccidental characterization of the shape of simple parts, such as horns, was accurately depicted with great consistency in the prehistoric art and would, presumably, remain high, we can only speculate why the spontaneous inclusion of the

concave terminator, among those without formal art training, has barely increased from moderate levels over the millennia, if at all. In contrast to the figure-like character of simple parts, concave terminators serve to define the boundaries in such smooth shapes (or objects) (Koenderink and van Doorn 1982). Object concepts typically include a representation of the parts and their relations (Tversky and Hemenway 1984; Biederman 1987), not the space between the parts. Indeed, often formal art training employs techniques such as turning a picture upside down, superimposing gridlines, or even the instruction to draw the space *between* the parts to facilitate the disengagement of the budding artist's prior knowledge of the real-world shape of an object so that she can better depict its image (Bro 1978). Last, we have no speculation on just what it is that allows someone without formal art training, then or now, to realize this subtle invariant.

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