Does Topological Perception Rest Upon A Misconception About Topology?
Roberto Casati

To cite this version:


HAL Id: ijn_00544211
https://jeannicod.ccsd.cnrs.fr/ijn_00544211
Submitted on 7 Dec 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Doestopologicalperceptionrestonamisconceptionabouttopology?

RobertoCasati

InthisarticleIassesssomeresultsthatarresthetheexistenceofatypeof 'topologicalperception',i.e., perceptuallybasedclassificationoftopologicalfeatures. Strikingfindingsaboutperceptionininsectsappeartoimplythat (1)configural, global propertiescanbeconsideredasprimitiveperceptualfeatures, and(2)topologicalfeatures inparticularareinterestingastheyareamenabletoformal treatment. Idiscussfour interrelatedquestions thatbearonanyinterpretationoffindingsabouttheperceptionoftopologicalproperties:whatexactlyaretopologicalpropertieswhatmakesthemglobal, inwhatsensethequotedfindingsmakesthemprimitive, andwhatarethehopesof a formaltheoryofperceptionbaseduponthem. Isuggestthatmathematicaltopologyisnot thecorrectmodelforcognitionoftopologicalpropertieshencethatsomeotherformalism oughttobes—af orm of‘internalizedtopology.’"However, oncetheprinciplesofthis typeoftopologyarespelledout,theymaynotbeasglobalisticasonemayhaveexpected.

Keywords: TopologicalPerception; Topology; VisualPrimitives

Manylogicallyindependentbutcoordinatedfactorsconstrainthequestforvisual primitives. First, phenomenologytellsus thatthevisualsceneiscomplex, butatthesametime thattherearerecurringelementsoutofwhichcomplexitymaybebuilt (Kanizsa, 1979). Second, mathematicalmodels show how it is possibletobuild complexrepresentations out of representations ofsimplercomponents (Biederman, 1987). Third, computationalarchitecture makes it plausible that the complexity ofretinal input (providing pixel size information about properties at places) be
organized at very early stages into elemental descriptor store to reduce the computational load of subsequent stages (Palmer & Rock, 1994). Finally, behavioral and neurophysiological evidence for specific, downtosinge-neuron sensitivity to relatively well delineated features of the environment has been gathered over the last decades starting from (Hubel & Wiesel, 1959). But do these criteria converge on a single list of primitives? They don’t have to, of course; and finding out what we expect to be phenomenologically or computationally primitive is not sobehaviorally or neurophysiologically will make for an interesting discovery.

This is in part the interest of (Chen, Zhang, & Srinivasan, 2003) finding that small brains such as those of the honey bees display a sensitivity to global configurational properties, in particular topological properties such as the presence or the absence of holes in 2-d displays. It looks as if not only bees are able to distinguish between configurations that differ only in their topological properties, but also they are able to generalize to topologically equivalent configurations that are rather different on many other respects. According to (Pomerantz, 2003), the findings are interesting for two reasons. The first reason is that the topological properties in question are generally considered as relatively complex and hard to compute (Minsky & Papert, 1998), but at the same time are very deep and robust properties of the environment—they are invariant under most transformations, as opposed, say, to metric properties, hence sensitivity to them would have a high adaptive value. The second reason is that the mathematics behind topological features is sufficiently well understood and formalized accordingly, as opposed to the relatively informal way of characterizations of global features, e.g., the one found in the gestalt literature.

But what exactly are topological properties, what makes them global, in what sense Chen et al.’s (2003) findings make them primitive, and what are the hopes of a formal theory of perception based upon them?

Let us first briefly review the results Chen et al.’s experiment. Honeybees were trained to choose one among a pair of configurations: an O-shaped stimulus and an S-shaped stimulus, say. Then they were tested on their ability to distinguish the O-shaped stimulus from other stimuli that are either topologically nonequivalent to the O-shape (such as a Å-shape, or a f-shape) and stimuli that are topologically equivalent to the O-shape (such as a x-shape) but look different as to their non-topological aspect. Bees succeeded in making the distinction with the first set of stimuli but failed to make it with the second set. This indicates both that they were sensitive to topological differences and that they correctly lumped together items that are topologically equivalent.

One should note in the first place that the displays used by Chen et al. for testing honeybees were 2-d pictures representing figures of different shapes and varying topological properties. There is, of course, a much general problem of using 2-d stimuli in order to draw inferences about a visual system that has adapted to a 3-d world. But there is also a specific problem: topology in 3-d is not automatically mapped onto 2-d topology. A2-d image like the shape of the letter B can be the projection of a 3-d letter O that has bent over in the middle. Hence from sensitivity
to 2-d topology one can only infer with much care to topological sensitivity to the topology of 3-d bodies; this by itself would question any ecological-adaptive considerations.

The globality of topological properties can be captured intuitively in opposition to the locality of other features. The directionality of an array, for instance, is an intrinsically local matter. At points the line has a direction that is given by its tangent at p. Little does it matter how the line looks at a (sufficient) distance from p.

On the other hand, the fact that the line closes unto itself (like a circle) or has terminations (like a bar) cannot be made dependent on the properties of a single point on the line; many other points have to be scrutinized. In this sense the properties studied by Chen et al. are global, and appear to be the subject matter of topology.

The main question arises whether the term ‘topology’ is used in the loose and popular sense of ‘rubbersheet geometry’ or by reference to formal mathematical notions. The issue of control in experimental design reflects this uncertainty. Chen et al. appropriately point out that it is hard to test for topological differences without introducing some non-topological differences in the stimuli: “there seem to be, in principle, two geometric features that differ only into topological properties” (2003, p. 6687). But from the viewpoint of mathematical topology, this is inaccurate. An open sphere and a closed sphere—or their 2-dequivalent, a closed circle and an open circle—have different topological properties but the same metric properties (same radius, asthe boundary of the closed circle has no dimension). To be sure, this fact may not have any consequence for the design of visual test stimuli, as the difference between a closed and an open item has no visual counterpart (dimensionless items, one may argue, are under perceptual discrimination threshold). But this brings us to an important point. When we talk about topological differences in visual displays, we may not be talking about the differences that are the subject matter of mathematical topology. Hence talking of ‘topology’ requires some other refinement, short of being loose talk, especially if it is to provide the ‘formal theory’ that (Pomerantz, 2003) invokes.

One may suggest that something like an internalized topology captures the features we have in mind—such as the ability to sort out objects based on the number of holes they have (the difference between the letters B and O, having one and two holes respectively) or to assess the equivalence between figures (say, the letter S and the letter L). But though we may need some care because the theory now requires a new notion, such as hole, and some account is needed of what it is for the visual system to process the feature of being a hole in such a way that it contributes to the explanation of the performance of distinguishing S or B from O.

To see the point more clearly, consider one interpretation of Chen et al. (2003). From the viewpoint of an intuitive topology, the difference between having and not having one hole is implied by the presence or absence of the visual features. Now, if it were demonstrated that processing of these features is available to the visual system, it would be possible to assess the claim that the global features invoked by Chen et al. and Pomerantz (2003) are perceptual primitives. The following is a proposal in that sense.
The visual features in question are:

1. The presence of complete visual boundaries of a unit, and
2. The uniformity and connection of the unit (Palmer & Rock, 1994), along with its maximality (Casati, 2002).

The presence of holes is correlated with these simpler features in the following way. If a maximal uniform connected unit possesses just one complete visual boundary, then it has no hole. If it possesses two visual boundaries, then it has one hole. In general, for any given visual display:

3. For maximal uniform connected figures and \( n \) complete visual boundaries, then the number of holes is \( n - m \).

The further element that is then needed is that the visual system implement somehow of counting the features and compare their cardinalities. Given what is known about the limits of the ability to subitize small quantities, it is expected that the difference between configurations with, say, one and two holes will be accessible to the system. At the same time, the difference between configurations with nine and ten holes is expected not to be accessible to the system. But surely these latter configurations are topologically distinct from the viewpoint of mathematical topology. Hence testing the ability of distinguishing between configurations with varying numbers of holes can decide between a holistic and a less holistic account of visual properties.

Furthermore, how far can topological generalization go? Letters I and J are topologically equivalent in the intended sense; but so are, presumably, I, L, K, and H (the latter three, for instance, can all be 'shrunk' to an I without cutting or gluing'). Will data confirm as sensitivity to these equivalences? Some may expect instead that some sort of parsing by components will predict that the shapes are resilient to placement into a single category: an H has three components, an H has only one. Here again the globalist hypothesis can be pitted against the other theoretical accounts.

It may be questioned whether features (1) and (2) are really simpler than the global feature of having a hole. After all, both (1) and (2) presuppose that the unit (connection) of both the boundary and the figure are accessed and assessing connection is notoriously difficult. Moreover, on the one hand, this is a general problem, one that affects all theories that are supposed to characterize the entry units of the visual system. On the other hand, in order to show that sensitivity to the feature of possessing a hole is not sensitivity to a visual primitive, it is enough to show that the former can be explained in terms of sensitivity to other features, without any further commitment to the hypothesis that these features are themselves visual primitives.

To conclude, what is the evidence that topological or global features such as having a hole are primitives of the system, according to Chenet al. (2003)? The clearly delineated criterion in the paper is the size of the computational system: honeybees have small brains. The criterion is novel relative to the four criteria listed at the top of this paper. The criterion predicts that a feature is primitive if it is computed by...
asmall system. However, for the reasons given above, the system in question may simply be not small enough to provide a cogent answer.

Note
[1] The criterion reflects the one given for cavities in 3D bodies (Casati & Varzi, 1994).

References