Extended Abstract

Finding Perceptually Closed Paths in Sketches and Drawings

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1 Summary

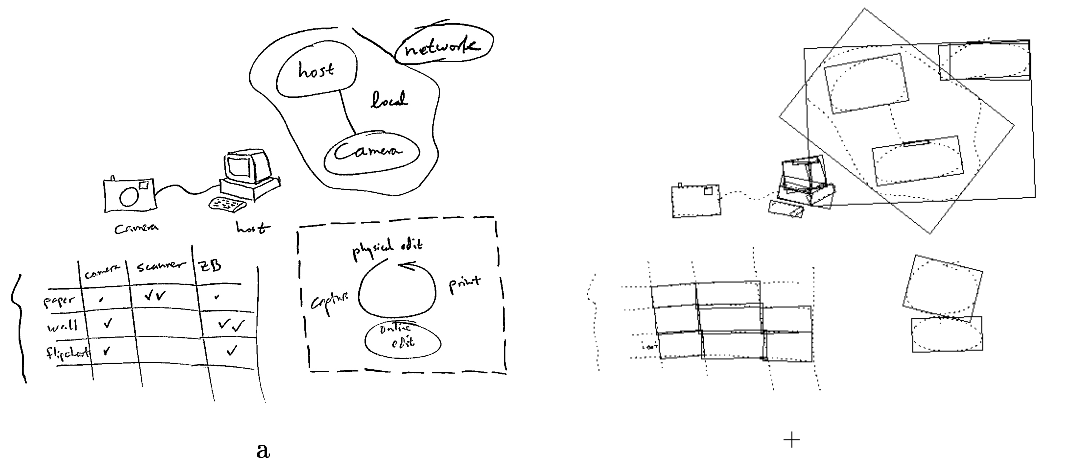
Closed or nearly closed regions are an important form of perceptual structure arising both in natural imagery and in many forms of human-created imagery including sketches, line art, graphics, and formal drawings. We have developed a fast and effective algorithm especially suited for finding perceptually salient compact closed region structure in hand-drawn sketches and line-art. Starting with a graph of curvilinear fragments linked end-to-end with neighbors, the key problem is to manage the search of possible path continuations through junctions in an effort to find paths satisfying global criteria for closure and figural salience. We identify constraints on the ways that junctions arise in line drawings that permit effective guiding and pruning of search.

2 Background

The Gestalt laws of perception have long recognized figural closure as one of the primary perceptual phenomena exploited by the human visual system. Objects tend to be spatially compact and relatively uniform in surface appearance with respect to the surrounding background. But figural closure also plays a significant role in the perceptual organization even of abstract figures that have no connection to coherent physical objects. This property of the visual system has come to be exploited across a culturally diverse set of conventions people have developed for representing information in graphic media. Figure 1a illustrates that compact closed or nearly closed paths in graphics, line drawings and sketches can indicate, among other things, individual physical objects; conceptual objects; groupings or collections; logical or other abstract relations; emphasis; looping paths or circuits; symbols and characters (or fragments thereof); and tabular cells. Our primary domain of focus is line-art, but the algorithm we present may apply to natural imagery as well.

In computer vision, algorithms have been designed to detect figural closure based on strict path cycles [2, 1, 5] and strict figural convexity [3, 4]. We seek instead a method that is more tolerant to variability including gaps and some degree of concavity.

Like previous algorithms, our approach views the problem as one of managing the search for paths satisfying local and global criteria for contour closure and figural goodness. We manage this search through careful consideration of the ways that paths can continue through junctions.



a

Figure 1: a. A hand-drawn sketch exhibits various roles for perceptually closed contour paths (see text). b. The 34 closed paths found from 135 curve fragments input to the closed path finding algorithm after a filtering preprocessing step removed small connected-components from a. Note that the preprocessing removed the elements of the dashed box. Processing time to find closed paths was 2 seconds.

3 Junction Analysis

Our starting point is a collection of simple curve fragments. These are relatively straight curvilinear path segments bounded by free ends, corners, or junctions, obtained by standard thresholding, thinning, tracing, and corner detection processes. Closed paths are to be constructed by tracing sequences of curve fragments linked roughly end-to-end, starting from fragments that serve as seeds.

Links among curve fragment ends are formed in three steps. First, sets of nearby of curve fragment ends are found by clustering. Second, links are labeled with measures of the geometric configuration between pairs of curve fragment ends. A score is given for how well each pair forms a corner configuration, and for how well the curve fragments align with one

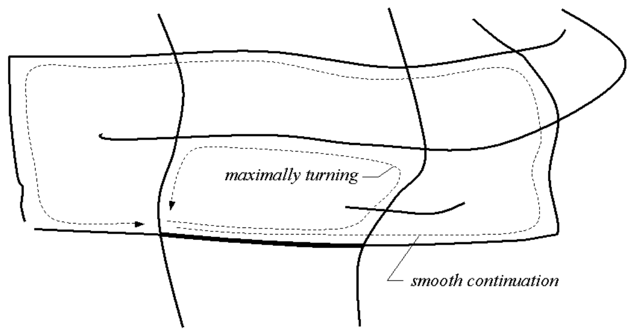


Figure 2: We distinguish two kinds of figural closure. A *maximally-turning* closure path traces the smallest figure possible. A *smooth-continuation* closure path prefers smooth continuation traces through junctions. Other closed paths through the seed (thick contour fragment) are perceptually insignificant.

another. The third step is based on a fundamental observation about two distinct kinds of salient closed contour paths that can occur, as shown in Figure 2.

One kind of perceptually salient closure occurs as a *maximally-turning* path, or one that defines the smallest region enclosed by the participating contour fragments. In this case, distinct bounded regions are the primary objects of interest. A second kind of perceptual closure occurs as a maximally smooth, or *smooth-continuation* path, where choices of directions through junctions obey the Gestalt law of good continuation. In line art, these paths normally reflect a single motion of the pen, and contour junctions merely reflect "accidental" crossings of distinct pen-stroke objects.

This observation is used to derive a new kind of score for each pair of curve fragments entering and exiting a junction, called a *junction preference score.* The junction preference score rates the preference for tracing through the junction in each of the possible directions, proceeding from an "entering" curve to each of the possible "exiting" curves, according to search parameters which can take any of four settings: pursuit of either maximally-turning or smooth-continuation paths, and paths turning in either the clockwise or counterclockwise direction.

4 Bidirectional Search

Local path tracing preferences provided by junction preference scores guide search for globally significant closed or partially closed paths. A global goodness measure is used to assess the figural quality of any candidate path, combining factors of compactness (lack of concavity), and the relative proximity of the path's ends.

The search procedure itself is bidirectional, as the path is grown outward from each end of a seed fragment. The most locally preferred path extending from each end is expanded first. Then, if these search nodes do not form a path of sufficient goodness, alternate paths are expanded in a best-first fashion.

This procedure results in an overabundance of candidate closed paths because the same or similar paths can be found from different seed curve fragments. These are consolidated by clustering by pose (location, size, and orientation), then selecting the best representative from each cluster.

This algorithm is an integral part of a larger program for editing and interpretation of hand-drawn sketches whose intent is to incorporate computational mechanisms for Perceptual Organization in support of robust recognition of informal drawings and sketches. The closed paths found serve as initialization points for more specialized detectors of geometric shapes such as ovals and rectangles, as well as the basis for asserting abstract "containment" relations among text and graphic elements.

5 References

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