Finding Perceptually Salient Closed Paths in Sketches and Drawings

Eric Saund
Xerox Palo Alto Research Center
3333 Coyote Hill Rd.
Palo Alto, CA 94304
saund@parc.xerox.com

1 Summary

Figural closure is an important form of visual structure found in sketches, graphics, and formal drawings. This paper outlines an effective algorithm for finding closed or nearly closed, convex or nearly convex paths in precisely or imprecisely drawn line art. We start with a graph of curvilinear fragments whose proximal endpoints form junctions. 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 quality. We identify constraints on the ways that junctions arise in line drawings that permit effective guiding and pruning of search.

2 Background

One useful step in the recognition of graphic images is to identify intermediate level structures that are more complex than early feature measurements but fall short of final interpretation in terms of object models or domain semantics. These structures provide indices for object database indexing, features for shape matching, constructs for syntactic analysis, and building blocks for assembling more complex hypotheses representing image content.

A particularly useful type of such geometric structure is closed (or nearly closed) compact paths, and the regions they define. These are found nearly universally among document images and play leading roles in the graphic renditions of, 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. See Figure 1.

Humans are adept at detecting closed regions and we do so effortlessly and unconsciously in the course of everyday seeing. In fact the Gestalt Law of *figural closure* is named for this phenomena. Closed regions might appear initially to have a straightforward definition in terms of geometric constraints on the configuration of curvilinear elements comprising their boundaries. But in practice, visually salient and semantically significant closed figures can deviate substantially from idealized parameterizations. This is especially the case for hand-drawn sketches which are notorious for their variability.

Like previous algorithms tackling this problem, 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.

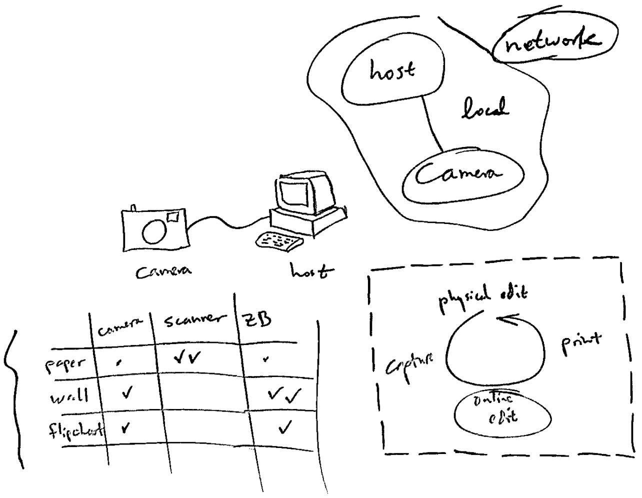

Figure 1: A hand-drawn sketch exhibiting various roles for perceptually closed contour paths (see text).

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 another. These scores are heuristically derived mathematical expressions on relative distance, orientation, and other factors. The third step is based on a fundamental observation that two distinct kinds of salient closed contour paths occur in the line art domain, as shown in Figure 2.

One kind of perceptually salient closed path is found as a *maximally-turning* path, or one that defines the smallest region enclosed by any contour of the path. In this case, distinct bounded regions are the primary objects of interest. In document images, objects found within a maximally turning region tend to bind together, for example the checks found within each cells of a table as shown in Figure 1.

A second kind of perceptually salient closure is found as a maximally smooth, or *smooth-continuation* path, where choices of directions through junctions obey the Gestalt law of

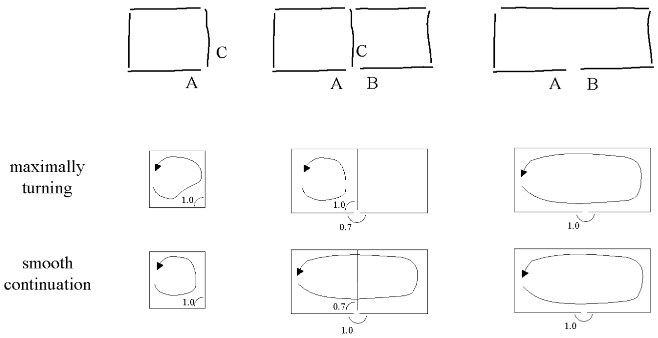

Figure 2: We distinguish two kinds of figural closure. A *maximally-turning* closure path traces the smallest figure possible. A *smooth-continuation* closure path prefers smooth continuation traces through junctions. Numbers indicate junction preference scores, under both kinds of path preference, for a path traced between pairs of curve fragments indicated by arcs. Any score below 1.0 indicates a penalty. Arrows indicate minimal penalty paths.

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. Figure 2 gives an indication of junction preference scores leading to detection of these different kinds of closed path. We have compiled a table assigning plausible junction preference scores based on the local corner and alignment geometry of junctions.

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, which combines 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

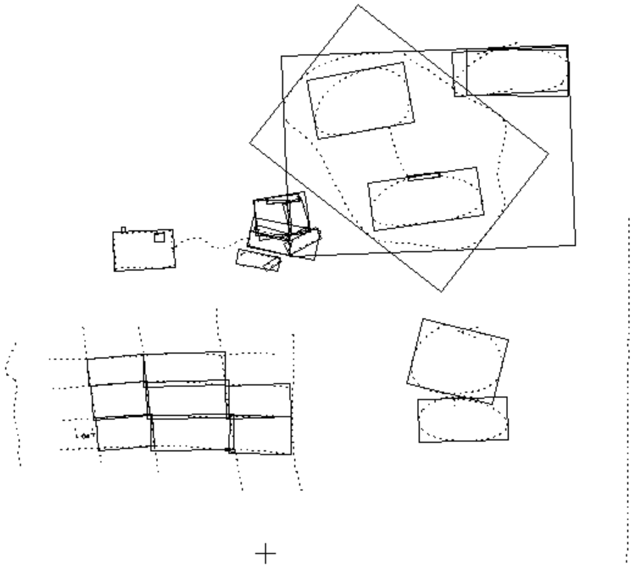

Figure 3: Twenty-nine closed paths closed paths found by the algorithm on curve fragments of Figure 1. Paths are depicted by their oriented bounding boxes. Note that a simple filtering preprocessing step removed small character-size connected components from the original image resulting in an input set to the algorithm of 135 curve fragments shown with dashed lines. This filtering removed the segments forming the dashed box in Figure 1. Three other perceptually salient closed paths not found by the algorithm (the rightmost cells of the table) are because we have omitted a mechanism to break curve fragments forming the top bar of a "T" into smaller pieces when the stem doesn't touch the T.

by clustering by pose (location, size, and orientation), then selecting the best representative from each cluster.

Figure 3 shows the result for the hand-drawn sketch in Figure 1. Compute time for finding closed paths in this image is about 3 seconds in a Java implementation on a 450 MHz Pentium.

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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