Title:
Data Processing for Medial Axis Computation using B-spline Smoothing

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Introduction:
Given a sequence of points, representing a free-form closed shape in the plane, this paper presents a system on how to prepare the data to enhance the robustness of the medial axis code [1] and the quality of its output. We applied this method in the manufacture of shapes used in semiconductor production.

Although there are many ways robustness can be enhanced, there are two techniques we want to single out in this presentation. The first relies on knowledge and calls for the separation between the general purpose code and a set of special purpose functions. Based on our decades of experience, we believe the it is nearly impossible to make a general purpose code robust in the presence of anomalies. One has to handle the special cases individually relying on knowledge about the relationships among the entities. A simple example is line-line intersection. A robust algorithm would work under the *decompose-solve-recompose* paradigm: (1) decompose the proplem into cases based on the relationship among the lines, (2) solve the individual cases with separate algorithms that are designed to handle parallel, perpendicular, nearly parallel, overlapping and general cases, and (3) recompose the subresults into the final output. The second method calls for a systemic approach shown in Fig. 1.

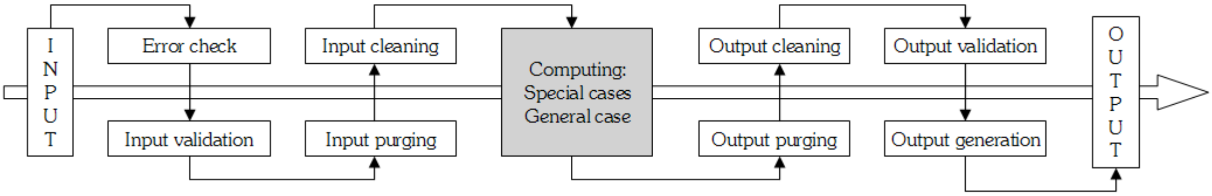

Fig. 1: Systemic approach to robustness.

It is evident that this systemic approach imposes quite a bit of overhead on the geometric computing environment. However, two notes are in order. First, no price is high enough for safety, especially in todays world where our very lives are controlled by algorithms, and second, our decades of experience has shown that although this overhead was an issue in the eighties, it has become a non-issue in the presence of powerful hardware and optimized software. The medial axis pre- and post-processors were built based on the principles above.

Methodology:
The system presented herein has the following major components:

1. Data validation: the medial axis code works with a point sequence that represents a free-form boundary. This sequence needs to be validated to not contain singularities.
2. Data purging: unwanted points in the sequence are coincident points or points that are too close to one another. An efficient algorithm eliminates these points in semi-linear time.
3. Data cleaning: the input data is considered “dirty” if it has lots of noise which affects the medial axis generator a great deal. Eliminating the noise is critical and is done via a subdivision-type method on the input points.
4. Data fitting: The clean point set is now fitted with a B-spline curve so that an error condition is maintained along with requiring that all details, inherent in the input, be reproduced in the output curve.
5. Data sampling: the B-spline curve provides a mathematical form that can be interrogated based on the needs of the application and independent on how the original data was given. A new point set is generated so that it produces a better-quality medial axis.
6. Medial axis computation: we used VRONI [1] to generate all the required medial axes.
7. Data post-processing: it is done in a similar way as data pre-processing, e.g. the medial axis, that is computed as a sequence of points, can be output as a set of B-spline curves (an arc graph).

Some examples of the differences in medial axis outcomes between the original data, the smoothed data and the sampled data are shown in Fig. 2.

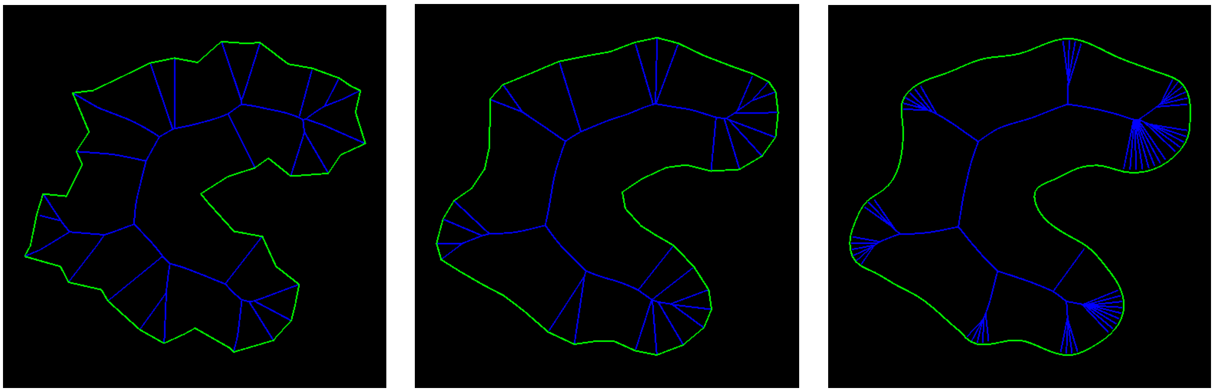

Fig. 2: Medial axis computed to the original data (left), smoothed data (middle), sampled data (right).

Summary:
A series of algorithms are presented for data processing to enhance the reliabilty of geometric algorithms and to provide a choice of the output based on the quality of the input. Because the medial axis code is very dependent on the form of the boundary data, we demonstrated the performance of our method on VRONI [1], a medial axis system developed by Martin Held. VRONI performed remarkably well in our tests, producing the kind of output one would expect from the quality of the input. Our conclusion is that VRONI is an excellent medial axis method for general polygonal data, however, to make it useful for free-form shapes, more research is needed to anwer (at least) two questions: (1) given a manufacturing tolerance, what is an optimal sampling of the boundary curve to minimize the anomalies of the medial axis, and (2) how to post-process the branches around high curvature cavities. Other applications may raise a few more challenges, however, it is evident that the *preprocess-compute-postprocess* paradigm enhanced the quality of our output and made our system (of which VRONI is a part) more robust and reliable. It should also come as no surprise that the pre- and post-processors can be more code-extensive than the main computational unit itself. However, the good news is that these computational elements are reusable and hence once written a large variery of applications can (and should) be pre- and post-processed.

References:

1. M. Held, VRONI: An engineering approach to the reliable and efficient computation of Voronoi diagram of points and line segments, Computational Geometry – Theory and Applications, 18, 2001, pp 95-123.

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