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LOCAL AND REGIONAL EDGE DETECTORS:

SOME COMPARISONS

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ABSTRACT

Consideration of the usefulness of edge information for use in segmentation or other intermediate-level picture operations has motivated a comparison of the accuracy and reliability of a number of directional edge operators. The Hueckel operator is singled out for comment, and an error in its derivation is noted. Another regional edge operator is introduced as being better suited to application on discrete pictures.

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1. Introduction

1.1. Background

In any system for interpreting picture information, a stock of low-level operators is needed. One essential component of such a group is a dependable edge-extraction procedure or set of procedures. As a result, a great many such algorithms, each with its particular merits, have been devised. In the past few years, some attempts have been made to systematize this array, with surveys by Davis (Ref 1), Fram and Deutsch (Ref 2), Pratt (Ref 3), and by Frei and Chen (Ref 4) viewing the field from somewhat different points of view, and suggesting rather different rankings of the edge-detection algorithms they examined. Maryland's Computer Vision Laboratory is particularly interested in developing intermediate-level procedures (e.g. relaxation, edge-guided segmentation) which require primitive edge information for their successful application. In this context, the visual fidelity of an edge-detection operation is of secondary interest, as only at a later stage will final images be formed. The most commonly used class of edge-detectors are local or regional operators (but see Ref 5) which produce, at some set of picture locations an 'edge response' which may include any or all of the following:

a) magnitude of the edge (either height or slope)
b) direction of the edge
c) reliability of the edge description
d) width, or blur.

As information about an image to be used by some other process, all of these measures can be useful. A number of procedures which produce measures of the first three quantities have been described. The present study has limited itself to such operators. Those included were:

a) Hueckel's edge-detection algorithm (Ref 6)

b) The Sobel operator, with least-square goodness of fit (Ref 7)

c) Mero and Vassy's approximate Hueckel operator (Ref 8)

d) Hummel's optimal local template (Ref 9)

e) A new discrete Hueckel-like operator (Section 3)

Comparison of the operators, never an easy process, was complicated further by the fact that b), c), and d) (as implemented, at least) are purely local operators, evaluated separately at each image point, while a) and e) are intended to be evaluated only on overlapping regions. The two kinds of operators are sufficiently different that direct comparisons are very hard to make. The approach taken was to measure the degradation in the edge response when various sorts of distortion were applied to the image. These self-comparisons, then, act as measures of stability and discriminatory power that allow comparison between the different techniques.

1.2. Characterizing an ideal edge

Edge detection procedures may be divided into two sorts: local and regional. The former, typically applied on very small (3x3 or 4x4) picture windows, can usually be interpreted as differential operators of some sort, used to define the 'edginess' at each point of the image. Regional operators, on the other hand, may be applied on windows several times the width of the edges to be detected, and are expected to give responses when the entire region is well described by two constant levels separated by an edge of some specific sort. For both, the question 'what is an edge' must be asked, but for regional operators, the answers are less clear.

Directional local operators, though plentiful, all appear to measure something like the gradient at a point, the differences being predominantly due to different ways of responding adequately to imperfections such as blurriness and noise, or to considerations of computational speed. Regional operators have not been so widely discussed, Hueckel's operator being the only widely quoted one of this type. (Mero and Vassy described a local operator, and a regional extension of it. It is the local version that we use in these comparisons.) For such operators, three properties of edges are of concern which are not of great importance for local detection. First, how broad should an 'ideal' edge be, and should the width be variable. Second, should a perfect edge be necessarily straight, or should some class of curves be allowed. Finally, if several edges appear within the region, should the response give a total value, a maximum value, or no strong edge value at all? Sections 2.2 and 3, in describing operators a) and e), introduce two different responses to these questions.

1.3. Evaluation criteria

The edge detectors described were all evaluated on the same set of images, and a common measure of adequacy employed. The images include a set of synthetic 'perfect polygonal' images, which have long straight edges inclined at five degree increments from vertical or horizontal. A 'real' image (a picture of a girl's face) was included as well, to give some idea of response to textured edges of various curvatures. The evaluations are described in Section 4. Brief descriptions of the first four detectors comprise Section 2. In the course of this study some errors in the derivation of Hueckel's operator were found (described in Appendix A), suggesting that an edge detector with the same qualitative behavior be devised which did not share the technical defects of Hueckel's. Such an operator is described in Section 3, and an explicit algorithm constitutes Appendix B. Finally, an attempt is made to tie together the results of the study, by making some estimates of the usefulness of the operators described as inputs for further picture interpretation. An attempt is made to describe the features of each operator which are important, so that the results may be carried over to operators not explicitly studied.

2. Definition of the edge operators

2.1. Local operators

2.1.1. General description

Although some variation exists in the form of the local edge operators used in practice, the three chosen here are representative of a common class. For each of them, an orientation-sensitive mask is defined, which achieves its maximum response at a horizontal edge. A second mask is defined to be a 90 degree rotation of the first. Commonly, only these two masks are applied; however, Hummel´s operator includes two additional masks, again 90 degree rotations of one another. From the result of convolving each of these masks with the given region, (denoting the first two results by ´horiz´ and ´vert´) a response and a direction are found as:

response -- sqrt(vert**2 + horiz**2)
angle -- arctan(vert/horiz)

In actual application, it is common to avoid taking the square root by using some other combination of the two responses. The angle is usually obtained as the arctangent, although sometimes an alternative -- forming more rotated masks, and selecting the maximum response and associated angle -- is used instead. Finally, if more than two coefficents are calculated (as by Hummel) a somewhat more involved calculation is required to extract the response.

All of the local operators applied here are of the general form described, differing only in the masks used. For consistency, reliability of the edge is obtained in the same (slow) way for every case: by obtaining the mean squared error from the estimated edge explicitly.

2.1.2. The Sobel operator

The first operator is explicitly derived as an approximate directional derivative. The horizontal mask employed is:

$$\begin{matrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{matrix}$$

The double weighting of the center points is motivated by low-order cancellation of derivatives. The operator is applied on a 3n x 3n window (usually 3x3 or 6x6), with each weight applied to the appropriate nxn average value. The magnitude of the response is obtained by taking a square root, as indicated above.

2.1.3. The Mero-Vassy operator

An operator intoduced by Mero and Vassy (Ref 8) is the simplest one possible, employing as a horizontal mask:

$$\begin{matrix} 1 & 1 \\ -1 & -1 \end{matrix}$$

That is, the first n/2 rows of the mask are +1, the last n/2 rows are -1 (for odd diameter n, the central row is set to zero.) For this operator, the response is measured as the sum of the absolute values of the vertical and horizontal responses. (Not only is this consistent with the 'minimum cost' philosophy behind this operator, but it is in this case more accurate than use of the square root form.) Clearly this mask is motivated by a simple model of an edge as a step discontinuity.

2.1.4. Hummel's operator

One can look at edge operators of this sort as attempts to describe the image by expansion in a basis set in which the terms included have high overlap with an ideal edge (an idea due to Hueckel, as noted below). Hummel (Ref 9) has extended this idea to give maximum overlap for arbitrary a priori estimates of edge direction. For uniform edge orientation his bases are of the sort already described, both when only two basis functions are retained (as in the previous examples) and when four basis functions are included. The latter is recommended as the more reliable procedure, and is adopted for the operator tested here. For a 6x6 window, Hummel's horizontal mask would be:

.00	-.75	-1.0	-1.0	-.75	.00
-.45	-1.0	-1.3	-1.3	-1.0	-.45
-.20	-.45	-.80	-.80	-.45	-.20
.20	.45	.80	.80	.45	.20
.45	1.0	1.3	1.3	1.0	.45
.00	.75	1.0	1.0	.75	.00

2.2. Regional operators

2.2.1. General comments

Regional operators are computationally sensible only if they can be applied at many fewer points than their local competitors. Hueckel originally proposed a sequential scheme for application of such templates, but they are perfectly suitable to parallel application on a regular pattern of overlapping regions, with some means of selection of 'the' edge among the several that might be reported on a given subregion (for this study, the maximum response at each point in the region was selected). A convenient pattern is to apply the operators on 2Nx2N regions, overlapping by N points on every side. The final result is then a lattice of outputs, each representing an NxN cell, for each of which a well-determined edge, orientation, and position within the cell are given. Because of this data compression, it is probably most accurate to consider the output from regional operators as being comparable to thinned or similarly processed output from local operators, rather than to the raw local edge output.

While regional operators automatically produce thin edges, and have some advantages over local operators simply because more of the image can be seen at one time, the large domains bring with them some disadvantages as well. The need to find only one edge in a region means that one may expect such operators to fail if 'clutter' (closely adjacent edges) or substantial textural variation is expected within a single region. Difficulty may also arise in distinguishing ramps from edges (a ramp will produce large gray level differences at extreme points of a large window, even if it is only just noticeable on a small one). Finally, the operator may not respond to 'real' edges which do not match the 'ideal' type assumed.

2.2.2. Hueckel's operator

Hueckel (Ref 6) introduced a novel edge-detection algorithm, which has prompted a number of recent commentaries (e.g. Ref 9). The algorithm can best be described by a summary listing of its characteristic features.

First: The choice of 'ideal edge' is unusual. In fact, for both theoretical and practical reasons, what is defined is an ideal edge-line. Two parallel lines divide a continuous disk-shaped domain into three regions. A template on which each of these regions has a constant gray-level is called an edge-line. To identify an edge with such a template, the edge is defined to be parallel to the given lines and to lie within the center region, weighted to lie nearer the greater gray-level discontinuity. The height of the edge is the difference between the gray-levels of the two outer regions; the breadth of the edge is taken to be the width of the center region. (An earlier paper [Ref 6a] used a more conventional edge definition.)

Second: This class of edge-models is specifiable with six parameters. A basis of functions over the disk is specified. It will not generally be possible to match more than six expansion coefficients of an arbitrary image on the region with the corresponding coefficients for any ideal edge-line. One can, therefore, speak of the best edge as the edge associated with an

edge-line which matches some set of expansion coefficients of an image most nearly.
Third. Hueckel stated that by restricting a particular expansion to nine terms, an analytic solution to the optimization was possible, while sufficient 'extra freedom' was present to allow the mismatch between a best edge and the given function to act as a measure of adequacy of the edge description. Hueckel's final algorithm, then, consists of the following steps:

a) Cover the region to be examined by overlapping approximately disk-shaped windows, within each of which the best edge is to be found.
b) In each window, evaluate the overlap of the observed function with nine predetermined basis functions.
c) Perform a calculation to determine the edge-line which best fits the data.
d) If the fit is sufficiently good, the height of the edge sufficient, and the breadth not too great, an edge is reported with the calculated parameters.

This innovative approach to edge detection suggests a number of possible modifications which might make it computationally less expensive. However, Hueckel's basic approach to optimization suffers from an error that would appear to hamper any obvious modification of the method (noted as Appendix A). The practical effect of this difficulty is largely to make the parameters obtained for borderline fits extremely erratic. Occasionally, however, apparently reliable fits are similarly skew.

3. A regional operator on a discrete domain

3.1. Assumptions of the algorithm

Hueckel's algorithm is an attempt to find an optimal fit of a reasonably adequate edge model for a region of moderate size, at moderate computational cost. To achieve that goal, a continuous class of edge-models was chosen so that the usual analytic procedures for extremization of a function could be applied. Again, for simplicity of this kind, the domain chosen for analysis was a disk, and the procedures used were strictly appropriate only for a perfectly resolved (not discrete) image. The algorithm resulting, however, is theoretically inadequate (Appendix A), and might be expected to be rather less reliable on textured images than on simpler scenes. It is not obvious that any simple modification of Hueckel's procedure will remove either inadequacy, yet regional edge extraction seems a worthwhile idea, at least for comparison with local methods. The edge model described below differs from Hueckel's in almost every possible way --- except that both are regional operators. (This similarity of type in many ways outweighs the differences in detail; in actual use, they are more alike than Hueckel's and Hummel's operators, despite the similarities in the underlying theory of the latter two.)

If analyticity seems unattainable, there is little advantage in using a circular domain of definition for the edge model, and definite practical disadvantages, as disks overlap rather poorly compared to rectangles. Further, for domains of the order of 10 pixels by 10, the graininess of a real digitized image need not be negligible, so an intrinsically discrete model seems appropriate.

What is an edge to be, then? Suppose we examine a small, rectangular image of a window. For each separate row, we can surely find a best left/right division into a bright side and a dark side, with the dividing line allowed to fall between any pair of adjacent pixels. If the window overlies a true edge, we would expect all the divisions to be consistent in their sense, and to well represent the image in each separate row. Moreover, we would expect the division point to vary in a smooth way from row to row. If no edge exists, any 'clear' edges from single rows should be contradicted by nonexistent or opposing edges from nearby rows.

An edge will therefore be called (in this section) 'perfect' if in each row (and column) it is a perfect one-dimensional edge, and further, the division point is strictly monotone as one moves from the top of the window to the bottom (or from left to right). The latter restriction is required for the definition to be symmetric for rows and for columns; it includes all straight edges and many well-behaved curved ones, and excludes jumbled 'edges' that one would not normally wish to call perfect. The resultant edge templates consist entirely of +/-1, forming two uniform connected regions divided by a monotone boundary. The corresponding 'perfect' edge would be a scalar multiple of such a template, plus a constant offset.

An algorithm for obtaining the template of this type having maximum overlap with a given input is given as Appendix B. The minimum mean-square-error of fit between a given window and an edge template of this class would provide the most rigorous criterion for the best match. As this criterion is not decomposable (i.e. a perfect fit over part of the window need not be part of the perfect fit over the full window), it appears to require a full dynamic programming or other state-space search to assure optimality. This seems computationally inappropriate; therefore the maximum sum criterion, which is decomposable, was selected as the more useful. The given algorithm finds, rather quickly, a reasonably good edge exemplar for any window. Optimization of this quantity will, in many cases, also optimize the better criterion.

3.2. Description of the algorithm

The point of the algorithm is very simple. Since the adequacy criterion being applied is decomposable, the idea is simply to find the best template for the bottom k rows, then extend that result to the bottom k+1 rows, iterating until the full template has been defined.

Let the input picture be represented as $I(i,j)$. First, it is transformed to have zero mean. An intermediate matrix is then given by:

$$A(i,j) = \sum_{k=0}^{j} I(i,k) - \sum_{k=j+1}^{N} I(i,k)$$
(on an NxN domain)

The remaining transform is then:

$$B(1,j) = A(1,j)$$
$$B(i,j) = A(i,j) + \max\{B(i-1,k);\ i>1,\ k \leq j\}$$

Each cell of A gives a 'score' for a one-dimensional edge template for its row, with the positive/negative boundary located between the cell and its right neighbor. Each cell of B then gives the score of a partial template, monotone as required of an ideal edge, but including only the given cell and the rows below it. The edge description is extracted from B by beginning at the last row, and selecting the element with the largest score. After an element is selected from row j, the element of row j-1 is selected which has the largest score of any cell whose column number is not greater than this cell's. The edge selected passes to the right of each of the cells thus chosen. The basic algorithm is repeated four times (for vertical and horizontal edges, with left and right slants) with minor modification. The edge with the highest score of the four candidates is the edge reported by the algorithm.

Though the description above may appear somewhat awkward, the algorithm executes rather faster than Hueckel's algorithm, and cannot exhibit pathological behavior as the latter may sometimes do.

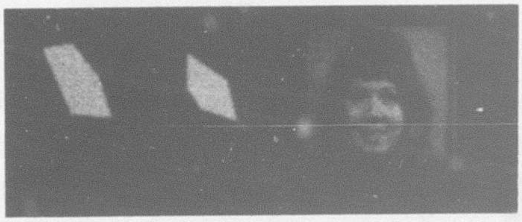
4. Experimental comparisons

4.1. Method

The experimental study included two kinds of comparisons of the adequacy of the operators. The first group of measurements were all of a type. In each case, a given operator was applied to the 'perfect' version of a picture (those used are shown as Fig. 1a,b,c). The operator was also applied to 'distorted' versions of the same picture, and the signal/noise ratio measured, with the original edge output defining the signal strength, and with the difference attributable to the distortion interpreted as noise. The distortions examined were (approximately Poisson) wide-spectrum, uncorrelated noise, edge blurring, and imposition of an overall linear ramp on the entire picture. All of these are common imperfections, and all interfere to some extent with edge extraction.

The intent of making the measurements in this way is to provide a measure of consistency which can be applied to all of the operators tested, despite substantial differences in the type of edge picture produced. Unfortunately, some mental rescaling of results remains necessary, as the broad response of a local operator invariably overlaps better with its perturbed version than do the narrow edge images produced by the regional operators. The experimental results are shown as Table 1.

In addition to these stability measurements, the simple nature of the polygonal images allowed a comparison of ideal values of edge parameters with the extracted values for the undistorted images, as well as for a single 'distorted' version, blurred over adjacent points then combined with Poisson noise (as in the earlier test) giving a signal-to-noise ratio of about 2:1. The results of these measurements are given as Table 2.



(a) (b) (c)

Figure 1. Test images.

a,b: Synthetic polygonal images. (Edges are inclined at integer multiples of 5° from horizontal.)

c ('girl'): Real image for reliability study.

Table I

Effect of Distortion on Edge Output

Domain/op	Uncorrelated noise		Blurring		Ramp	Girl + Noise
6x6	S/N = 3:1	S/N = 1:1	over 3 pts	over 5 pts	0.5 g level/pixel	S/N = 2:1
Sobel	4.9	1.5	13.4	3.4	1.7	1.5
Meró-Vássy	7.0	1.8	15.9	1.8	1.4	1.5
Hummel	5.6	1.6	17.4	3.4	67.8	3.2
9x9						
Sobel	2.0	1.3	7.2	2.4	1.8	4.2
Meró-Vássy	19.0	2.7	4.0	3.5	1.7	4.1
Hummel	14.7	2.6	44.0	6.1	1.8	7.0
Hueckel	0.5	1.2	0.9	1.0	2.6	0.4
Discrete	1.7	1.2	2.4	1.2	14.0	1.1
12x12						
Hueckel	0.3	0.3	0.7	0.7	1.4	0.4
Discrete	2.9	1.4	2.6	1.3	11.5	1.3

S/N ratios for edge output of distorted images compared to undistorted ones. Output = Output (undistorted) + Distortion. High S/N ratios, therefore, indicate less change in the output.

Table II

Accuracy of Edge Parameters

Domain/operator	Ideal input edges (0°-(5°)-90°) Edge height Systematic error	Spread	Angular error	Perturbed* edges (0°-(5°)-90°) Edge height Systematic error	Spread	Angular error
6x6:						
Sobel	3%	3%	2°	3%	10%	9°
Meró-Vássy	0	3	8	13	10	10
Hummel	7	3	4	30	7	9
Hueckel	0	2	2	7	10	7
Discrete	0	0	0[a]	24	7	10[c]
9x9:						
Sobel	3%	3%	2°	0%	7%	5°
Meró-Vássy	7	3	6	3	7	7
Hummel	8	3	3	17	3	7
Hueckel	0	5	3[b]	3	10	4
Discrete	0	3	0[a]	17	10	8[c]
12x12:						
Sobel	3%	3%	2°	3%	3%	3°
Meró-Vássy	0	0	6	3	3	7
Hummel	10	8	3	17	3	5
Hueckel	3	3	1	0	10	3
Discrete	0	0	0[a]	13	7	5[c]

[a] This operator extracts the discrete) 'perfect' edge

[b] One example deleted due to spurious fit

[c] Line through average cells chosen

* Linear 2-pt blur, Poisson noise w S/N = 2:1

4.2. Results and Discussion

4.2.1. Local operators

4.2.1.1. General

All of the local operators tested were able to detect distorted edge directions on small (6x6) domains to an accuracy of about 10 degrees. Edge magnitude was normally accurate within about ten percent. On larger (9x9) regions, angular resolution was improved (though at substantial computational cost) but ramps began to become a significant source of spurious response. Accuracy measurements were included on 12x12 domains for comparison with regional methods, though local operators are very costly on such large domains.

4.2.1.2. The Sobel and Mero-Vassy operators

Though these operators are of comparable accuracy when applied on regions of the same size, Sobel´s operator seems uniformly superior, and not much higher in cost than the simpler Mero-Vassy operator. Some of the difference is systematic, and could be diminished by use of a slightly modified angle calculation in the Mero-Vassy case, but on typically noisy images this effect would likely be negligible compared to the local irregularities.

4.2.1.3. Hummel´s operator

This operator is computationally more expensive to apply than the other local operators and, on very small domains, not very different in response. On larger regions (9x9) it is better able to reject low-frequency imperfections, such as ramps and off-center edges.

4.2.2. Regional Operators

The two operators performed similarly in these tests. Despite the theoretical shortcomings noted, Hueckel´s operator was accurate to within a few degrees in the presence of mild noise or blurring, while edge height was similarly accurate. The discrete edge operator, as it does not report an angle directly, was compared by matching the actual edge points reported within the images examined. No substantial differences were found on relatively undistorted windows. The discrete operator, however, was less affected by the presence of imperfections. Both operators produce goodness-of-fit measures that can be used to cause a 'no edge' response if the edge fit doesn't meet some criterion. For both, these bounds were made as permissive as possible, as for use with higher-level processing 'best guess' edges are of far more use than simply 'not-edge'. In a few cases, these lax criteria allowed ridiculously bad parameter estimates to be output by the Hueckel operator. Where this occcured, these responses were not included in the accuracy estimates, but the resulting measure is marked by an asterisk.

4.2.3. General remarks

In comparing operators for use with higher-level picture processing systems, it is clear that, for better or worse, regional operators are best thought of as already processing their output somewhat, compared to local operators. As a result, regional operators provide their information in a rather more compact form, and may well be preferred for that reason for the relatively expensive processing of later stages.

The specific comparisons revealed nothing surprising. Accuracy in angular information, in the presence of slight distortion, was largely a function of the area of application, not of the operator selected. All operators were comparably able to find the size of the edge in their domain. A particular feature of the Hummel, Hueckel, and discrete regional operators is that all report some sort of goodness-of-fit measure as a result of the fitting process itself. For the other operators, accurate extraction of such a quantity would be more expensive than actual application of the edge operator.

5. Appendices

A: Hueckel's edge/line algorithm

In Hueckel's 1973 description of an edge/line detection algorithm (Ref 6), as in an earlier, similar paper (Ref 6b), great stress is placed on the theoretical basis for the algorithm being introduced. A major point of this algorithm is that determination of the optimum values of the edge-line parameters can be carried out analytically, reducing by elementary means to the solution of a quartic equation in a single variable, plus a few simple ancillary equations. Independent of the effectiveness of the algorithm in practice, it is important to realize that the analytic method described need not, in fact, give optimum parameter values, and that the 'proof' of its adequacy was incorrect in an essential way.

A brief outline of the attempted proof is sufficient to make the difficulty clear. Given expressions for the nine basis coefficients for an ideal edge-line described by the parameters Θ and (x1,...,x5) = 'tuple', it is required to find values for Θ, tuple which minimize the expression

$$N = (a(i) - s(i: \Theta, \text{tuple})),$$

where the a(i) are measured coefficients, and the s(i) are 'ideal' values. The approach taken was to notice that the above expression could be rewritten as

$$N = a(i) + f1(\Theta, \text{tuple}) + f2(\Theta).$$

In this expression, the first term, being independent of the parameters, does not affect the minimization. For each Θ, the equation f1(Θ, tuple) = 0 was shown to be analytically solvable. Thus, minimization of N was stated to amount simply to minimization of f2 as a function of theta, followed by evaluating the best 'tuple' values for that optimum theta value.

The above procedure would, in fact, minimize N iff f1 could be shown to be nonnegative. For real parameter values, this is in fact the case. Unfortunately, solution of f1 = 0 requires, in general, complex values for some parameters. When complex parameter values are allowed, f1 is no longer non-negative, and zero need not be an extreme value. Therefore, whenever complex parameters are obtained by Hueckel's algorithm, it has failed to determine the optimum parameter values for the edge. (The explicit algorithm included in Ref 4 always selects the real parts of complex parameters as the optimized values actually reported. This aspect of the algorithm is nowhere described or justified in the text, and does not repair the inaccuracy noted.) Moreover, assuming the optimum f1 contribution always to be zero, when it sometimes is not, causes the algorithm to make excessively optimistic estimates of the reliability of such misassignments.

A related difficulty, rarely encountered, is that while the entire domain visible to the operator is described by an 'r' parameter between 0 and 1, it is perfectly possible for the algorithm to report an edge at r=2, for instance, completely outside the observed region. There is no reason why such an 'edge' should not be found to be highly reliable. Both these sorts of eccentric behavior are rare, and can be explicitly watched for by the algorithm, which could then assume that no edge, in fact, was present. They are, however, outside the framework of the discussion of the method provided by Hueckel. This sort of difficulty seems to appear in any small modification of the method intended to retain the general structure while decreasing the computational load, or while using a better-behaved, rectangular domain. It is largely for this reason that the regional operator introduced in this paper takes such a different form from Hueckel's.

B: A discrete, regional edge detection algorithm

```
procedure edge(input,succeed,template);
integer array input, template;
boolean succeed;

    <<params criterion = minimum total edge response in the
                         region consistent with the existence
                         of an edge. >>

begin
integer array NORMAL[1:size,1:size],A[1:size,0:size],
              B[1:size,0:size,1:4];

        << *** normalize input *** >>

form_normalized_input(INPUT, NORMAL);
  << by summing over the region to get the mean value,
       then subtracting throughout >>

SUMSQR := sum_of_squares(NORMAL);
succeed = 'false';
if(SUMSQR lss criterion) then return
else

       << *** form input transforms ***>>

begin
  for JP:= 0 step 1 until size do
     for K:=1 step 1 until 4 do
        B[1,JP,K] := A[I,JP];
     for I:= 2 step 1 until size do
     begin
        B[I,JP,1] := A[I,JP]+max{B[I-1,K,1] : K le JP};
        B[I,JP,2] := A[I,JP]+min{B[I-1,K,3] : K le JP};
        B[I,JP,3] := A[I,JP]+max{B[I-1,K,3] : K ge JP};
        B[I,JP,4] := A[I,JP]+min{B[I-1,K,4] : K ge JP};
     end;
```

```
   << *** then extract the optimum edge template *** >>

  procedure test(ind1,ind2,sign,position,value,which);
     integer ind1, ind2, which;
     integer array position
     real sign;
     real array value;
     begin
        if B[ind1,ind2,which] > sign*value[which] then
        begin
           value[which] := B[ind1,ind2,which];
           position[which] := ind2;
        end;


       for K:=1 step 1 until 4 do edge[K] := B[N,0,K];
        for JP:=1 step 1 until N do
        begin
           test(N,JP,1.,pos,edge,1);
           test(N,JP,-1.,pos,edge,2);
           test(N,JP,1.,pos,edge,3);
           test(N,JP,-1.,pos,edge,4);
        end;
     best := select_max(edge[K], K:=1 to 4);
   << set 'best' to index of template with maximum score >>

     for I:=N-1 step -1 until 1 do
        for JP:=0 step 1 until N do
        begin
          if best=1 and JP le edge[1] then test(I,JP,1.,pos,edge,1);
          if best=2 and JP le edge[2] then test(I,JP,-1.,pos,edge,2);
          if best=3 and JP ge edge[3] then test(I,JP,1.,pos,edge,3);
          if best=4 and JP ge edge[4] then test(I,JP,-1.,pos,edge,4);
     end;
     template[JP] := edge[best];
  end;
end;
```

6. References

1) L Davis, "A survey of edge detection techniques", Computer Graphics and Image Processing, vol 4, 1975, pp 248-270.

2) J R Fram, E S Deutsch, "On the evaluation of edge detection schemes and their comparison with human performance", IEEE Trans. Computers, vol C-24, 1976, pp 616-628.

3) William K Pratt, "Luminance Edge Detection Techniques", in USC Semiannual Technical Report, March 1976. (USCIPI Rept 660)

4) W Frei, C-C Chen, "Fast boundary detection: a generalization and a new algorithm", IEEE Trans. Computers, vol C-26, 1977, pp 988-998.

5) J W Modestino, R W Fries, "Edge detection in noisy images using recursive digital filtering", Computer Graphics and Image Processing , vol 6, 1977, pp 409-433.

6) M H Hueckel, "A local visual operator which recognizes edges and lines", JACM, vol 20, 1973, pp 634-647.
Erratum: JACM, vol 21, 1974, p 350.

6b) ----- "An operator which locates edges in digitized pictures", JACM, vol 18, 1971, pp 113-125.

7) R O Duda, P E Hart, Pattern Classification and Scene Analysis, Wiley, New York, 1971

8) L Mero and Z Vassy, "A simplified and fast version of the Hueckel operator for finding optimal edges in pictures", Proc 4th Intl. Conf. on Artificial Intelligence (Tbilisi, USSR, Sept 1975), pp 650-655.

9) R A Hummel, "Edge detection using basis functions", U Md Technical Report TR-569, 1977.

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Consideration of the usefulness of edge information for use in segmentation or other intermediate-level picture operations has motivated a comparison of the accuracy and reliability of a number of directional edge operators. The Hueckel operator is singled out for comment, and an error in its derivation is noted. Another regional edge operator is introduced as being better suited to application on discrete pictures. Keywords:

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