

# Object Location using Proportions of the Direction of Intensity Gradient (PRODIGY)

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## Abstract\*

*An object location method is presented. It uses the directions of the maximum intensity change directly to locate objects. The technique, PRODIGY, is described and implemented for object location of human noses. PRODIGY is a knowledge based system developed from the statistical analysis of thirty typical noses of different sizes. The PRODIGY algorithm locates a number of possible noses from the horizontal peaks in intensity. A mathematical analyses of the possible noses, each split into five zones, produces a list of possible noses on the image with a figure pertaining to the likelihood of the possible nose being a real nose. The method is successfully tested on a variety of faces and the results are presented.*

## 1 Introduction

Object location, in the terms of this paper, is the search for a pattern or object in an image using a pre-defined description of the object. This includes locating an object in an image or locating a given feature from that object.

Object location can be achieved in a variety of ways, such as:-

- **Template matching**[1]: Correlating sets of points on the image with a template, the template being a sub image that looks like the desired feature.
- **Histogram Analysis**[2]: Thresholding highlights features of similar intensity on an image.
- **Hough Transform techniques**[3]: Hough transforms locate straight lines and curves on images. A technique using these curves could be finding the centre of an object in an image from its edges and transforming the object into a 1D signal about the centre and correlating

with the desired shape.

- **Contour followers**[4]: Following lines of similar intensity can detect various shapes on the image.

Problems that arise when designing object locators relate to difficulties with size, orientation, position and ambient lighting levels. Adapting the various methods of object location can overcome these difficulties. Performing grey scale normalisation and affine transforms will enhance template matching. However, the algorithms would then take a long time to process as there are so many possible combinations. Using tracking[5], pre-processors and considering specific sections of the image could improve template matching but there are still limitations.

Varying ambient light levels can affect the quality of object locators. Edge detecting, which detects the peak changes in intensity across an image rather than amount of intensity change often overcomes lighting problems. However, there is a class of problems where edge detection is not appropriate as it does not sufficiently define edges or there are no distinct edges. This is the case when detecting noses on a human face.

Craw et al[7], describes a method of object location that ignores the absolute levels of intensity in an image but rather utilises the direction of the maximum intensity change to describe the desired features. These directions of maximum intensity change do not vary if the image is dark or light.

The next section explains the gradient analysis technique outlined by Craw et al[7] and presents the results that they achieved. Sections 3 and 4 expand on Craw et al's method to produce a location technique, called PRODIGY, that is independent of the size and position of the object. Section 3 explains the background to the PRODIGY technique, which involves selecting various areas of an image and building a table of the intensity change directions in those areas. Section 4 explains the PRODIGY algorithm, which compares the table with the average and standard deviation of sample objects to produce a value that represents the likelihood that the area chosen represents the desired object. Section 5

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investigates the statistical implications of the PRODIGY technique to show how valuable the results are. Section 6 describes experiments carried out on the PRODIGY algorithm and the positive results observed. The final section describes the future development of the technique and its implications.

## 2 Previous work

Gradient Direction Analysis entails using the direction of the maximum rise in intensity across an image directly for object location. The use of the SOBEL[6] operator is a common way of determining the direction of intensity rise in an image. For each block of nine pixels in an image this detector finds the 'magnitude and direction of maximum intensity rise'. It is common to quantify the angle of maximum intensity rise into one of 8 gradient directions (GDs) to simplify any analysis. An intensity rise with an angle of 0-45 degrees becomes a GD of 1. An angle of 45-90 degrees becomes a GD of 2 and so forth as shown in Fig 1.

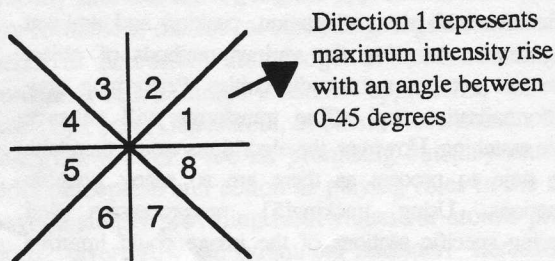


Figure 1: The eight directions of max. intensity rise (GDs).

Analysis of each pixel on the image gives a GD. The set of GDs calculated form a large array. Each element of this array corresponds to a point in the original image.

Craw et al[7], implemented gradient direction analysis to locate the lips on an image of a human face. The experiments described required faces presented in the centre of the image with the face taking up most of the space. The object locator, presented, searched for the lips in the lower middle section of the image. Sent out, to the left and right, from the centre point of each row of the image were two line followers. One line follower would search for consecutive pixels of GDs {2, 3} to find the upper lip and the other line follower would search for consecutive pixels of GDs {6, 7} to find the lower lip. The method recorded a mouth if both upper and lower lips were present, not separated by excessive distance and fitted in a long thin box.

This method tested by Craw et al on 20 images was successful on 19 of them (95%). The failure occurred because the mouth was not in the original search window.

## 3 Background to the PRODIGY Algorithm

The Gradient Analysis algorithm described in this paper (PRODIGY) depends on a pre-processor that locates points on the image, which may be noses. One can observe that the intensity on an image rises to a local peak along the centre of a nose. This observation led to the design of a pre-processor called the peak detection method. This method locates all the horizontal peaks in intensity across an image. Joining these peaks by drawing vertical lines on an image result in a few hundred lines (V lines) on the image, one of which will fall on the nose.

This set of V lines, called the nose set, consists of many possible noses. If there are L noses in the nose set of an image and there is only one face in the image there will be L-1 'false noses' on the image and 1 'real nose'. It is the intention of the PRODIGY process to distinguish the characteristics of real and false noses so that for each of the L noses a likelihood of the nose being 'real' can be found by the algorithm.

Examining the gradient directions (GDs) around 'real' noses showed that certain areas around the nose had a bias of points in one or two directions. Also the bias changed from one area to another. This result verifies expectations as a 'real' nose consists of surfaces lying in different directions. Observations revealed five distinct zones. Fig 2 and table 1 show the five zones.

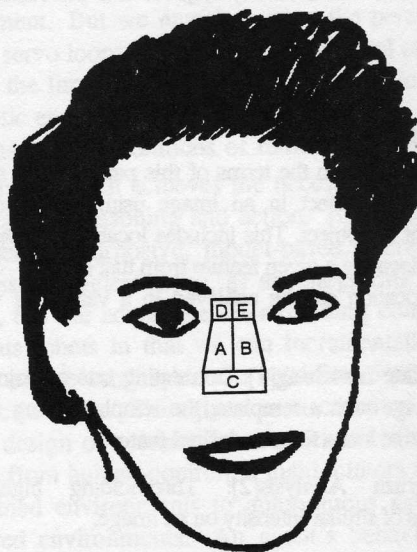


Figure 2: Position of nose zones

ZONE	AREA
A	The left side of the nose
B	The right side of the nose
C	Underneath the Nostril Area
D	Above the bridge of the nose to the left
E	Above the bridge of the nose to the right

Table 1: *Description of Zone Areas*

The PRODIGY technique finds the proportion of each GD in all the zones described above for a specific nose. However, before finding the proportions a definition of the zones must first be found. By first observing the areas around the nose manually and describing the common GDs in each zone this was achieved. Table 2 shows these observations.

ZONE	COMMON GDS
E	Mostly 8 with some 1 and 7
B	Mostly 5 with some 4 and 6
C	A mixture of 2 and 3 with some 1 and 4
D	Mostly 2 with some 1 and 3
E	Mostly 3 with some 2 and 4

Table 2: *Common gradient directions in each zone*

The following description shows how the algorithm designed for use with the PRODIGY technique locates the zone boundaries. The method comes from the observations in table 2. It will be possible, at a later stage, to improve on the following definition by performing a more detailed analysis of the area.

The peak detection pre-processor gives a V line down the middle of each nose. This is also the separation between the left and right zones of the nose.

An examination of the area towards the top and above the given V line reveals the separation between the A&B zones and the D&E zones. Starting at the bottom of the area the algorithm test a horizontal line of points to find if there are more points with GDs of {2, 3} than of {5, 6, 7, 8}. The algorithm notes a separation if there are more points with GDs {2, 3}, if not then it tests the next horizontal line above.

Examination of the area towards the bottom and below the given V line reveals the separation between the A&B zones and the C zone. The algorithm starts from the top of the area and tests a horizontal line of points to detect if the following is true

Number of points with GDs of {2, 3} is greater than

Number of points with GDs of {5, 6, 7, 8} plus half the number of points of GDs {1, 4}

If it is true the algorithm records the separation, if not the algorithm tests the next horizontal line below and so on.

The algorithm assumes that the bottom of the C zone is a third of the length of the V line below the top of the C zone.

The algorithm assumes that the top of the D&E zone is a quarter of the length of the V line above the bottom of the D&E zone.

The algorithm locates the sides of the nose by assuming that the side of a nose is at 78 degrees from the horizontal. An examination of a line of points at a 78 degree angle will locate the nose. The point where there are more points with GDs of {1, 2, 3, 6, 7, 8} than of {4, 5} gives the left side of the nose. The place where there are more points with GDs of {2, 3, 4, 5, 6, 7} than of {1, 8} gives the right side of the nose

Fig 3 shows a picture of a face with the above zones found by the technique described. Scrutiny shows that the zones fall over the required area.

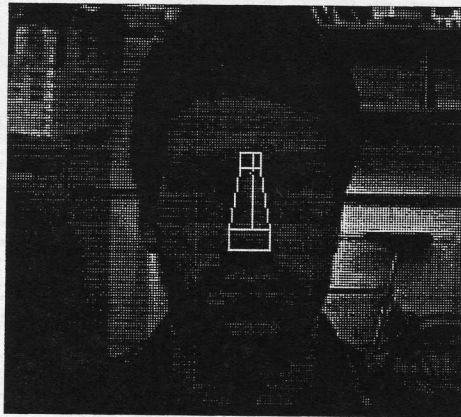


Figure 3: Picture of Face with zones located

#### ● Statistical Analysis

Tables 3 and 4 show a statistical analysis of a sample of 30 'real' noses. The noses, manually located from a bank of 30 faces, were between 8 and 24 pixels long. The tables show the five zones as selected by the algorithm described above. Each zone has an entry for each GD showing the percentage of pixels with that GD.

ZONE	GRADIENT DIRECTION							
	1	2	3	4	5	6	7	8
A	25.7	4.7	1.9	4.7	2.9	3.7	11.6	44.8
B	4.8	1.7	2.7	22.0	49.9	9.4	4.9	4.6
C	13.4	29.0	26.9	11.2	5.1	3.1	2.8	8.5
D	14.4	51.7	23.6	3.7	2.2	0.7	1.0	2.7
E	3.5	17.8	47.2	27.8	1.6	0.3	1.1	0.7

Table 3: *Average percentage of GDs in each zone, for real noses*

ZONE	GRADIENT DIRECTION							
	1	2	3	4	5	6	7	8
A	8.5	2.8	2.6	3.7	2.4	2.8	5.4	9.6
B	4.6	1.5	2.0	7.2	12.0	5.2	3.5	3.1
C	6.9	8.9	8.0	5.2	4.1	3.2	3.8	4.3
D	14.0	22.6	20.3	6.9	6.5	3.9	2.9	5.8
E	4.3	18.7	20.9	21.5	3.6	1.7	3.0	2.9

Table 4: Standard deviation of GDs in each zone, for real noses

Tables 5 and 6 show the same analysis of the five areas, but for 'false' nose. False noses are V lines, randomly selected, that do not fall on the 'real' nose.

ZONE	GRADIENT DIRECTION							
	1	2	3	4	5	6	7	8
A	27.8	5.5	3.8	7.7	10.5	7.2	15.3	22.2
B	13.1	4.7	5.7	16.8	25.6	13.6	9.2	11.3
C	17.8	11.6	13.5	14.6	14.5	8.0	8.4	11.6
D	18.8	14.4	12.5	8.1	11.0	9.4	11.1	14.7
E	14.6	12.4	17.2	11.7	13.4	9.6	9.8	11.3

Table 5: Average percentage of GDs in each zone, for false noses

ZONE	GRADIENT DIRECTION							
	1	2	3	4	5	6	7	8
A	22.1	8.5	8.9	13.4	13.2	11.3	18.4	17.9
B	17.0	8.3	9.7	17.6	21.1	18.2	14.4	13.4
C	18.9	13.6	16.2	17.2	17.3	13.4	14.6	13.8
D	27.4	24.0	21.9	18.4	22.8	20.8	23.0	24.8
E	24.2	22.2	28.3	22.8	24.9	21.1	22.0	21.7

Table 6: Standard deviation of GDs in each zone for false noses

From a visual examination of the data used to construct the tables the probability distribution functions (PDFs) were similar to normal distributions. Therefore all the algorithms designed assume that the (PDFs) are approximately normal. This assumption simplifies the mathematical analysis and the PRODIGY algorithm.

The data in tables 3&4 show a definite trend in the GDs for each zone and have low standard deviations. Tables 5&6 show GDs that are more spread out and have higher standard deviations.

The PRODIGY algorithm described in this paper aims to test a given nose to discern whether it is real or false. This leads to two hypotheses as follows

$H_0$  The nose is real

$H_1$  The nose is false

Likelihood ratios can give a figure that assists the selection of the correct hypotheses. In [8] Edwards defines the likelihood ratio. Application of this ratio, using the data in tables 3-6, produces a figure for each zone of a given nose.

The likelihood ratio of real and false noses and is  $R(x)/F(x)$  where  $R(x)$  and  $F(x)$  are the PDFs of real and false noses. Equation 1 shows the likelihood ratio for a given zone 'z' if the PDFs are normal distributions.

$$\frac{\sqrt{|G_z|}}{\sqrt{|S_z|}} \exp \frac{1}{2} [(x_z - F_z)^T G_z^{-1} (x_z - F_z) - (x_z - R_z)^T S_z^{-1} (x_z - R_z)] \quad (1)$$

Where  $G_z$  is the covariance matrix for false noses.  
 $S_z$  is the covariance matrix for real noses.  
 $X_z$  is the GD vector for the nose being analysed.  
 $F_z$  is the average GD vector for false noses.  
 $R_z$  is the average GD vector for real noses.

z represents the zone for a given nose.

Assuming all the zones are independent multiplying the zone likelihood ratios together results in a single likelihood function. Adding the logs of all the likelihood ratios simplifies the function to create a log likelihood function shown in equation 2.

## 4 PRODIGY

The following defines the PRODIGY technique proposed for locating an object in an image.

### PRODIGY technique

1. Locate a set of points on the image that could be the object required.
2. Select a set of zones on the possible objects. Each zone should have a small variation of gradient directions.
3. Calculate the percentages of each GD in each zone.
4. Find the likelihood that each set of zones is the desired object. (Prior statistical knowledge of the object required enables construction of a likelihood function.)
5. Select the point with maximum likelihood.

The PRODIGY technique, by design, is independent of the size of the object. Using the percentage of GDs in a zone rather than the absolute values enables this independence. However, because there is a specific number of pixels in a zone the percentage values will be discrete. Therefore, small objects will decrease the resolution of the percentage values. This will increase the error but not be catastrophic.

If the main object in the image, such as a face, consists of smaller sub-objects then application of the PRODIGY technique would locate each sub-object. A higher level method, substituting part 5, would combine the likelihoods of each sub-object. Fischler et al[9], describes such a technique for matching pictorial structures.

The following shows the PRODIGY technique as applied to the nose location problem.

### PRODIGY Algorithm for Nose extraction

1. Locate a set of V lines using the peak detection technique
2. For each V line.
  - a) locate the five zones on the nose and calculate the percentage of each GD in the five zones.
  - b) Calculate N values from the percentages and the

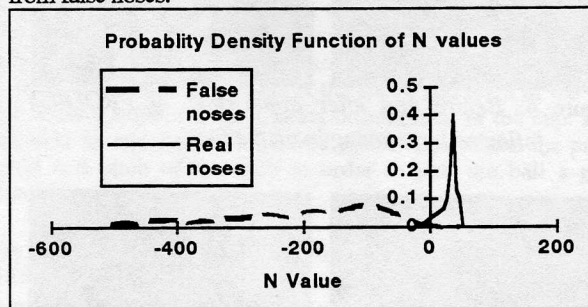
statistical data in tables 3-6 using the formulae in equation 2.

$$N = \sum_{z=1}^5 \left[ (X_z - F_z)^T G_z^{-1} (X_z - F_z) - (X_z - R_z)^T S_z^{-1} (X_z - R_z) \right] \quad (2)$$

3. Select the V line with the highest N value (maximum likelihood).

## 5 Performance

Analysis of the PRODIGY technique, on all the real and false noses in the bank of 30 faces, gives an indication of performance. Graph 1 shows the probability distribution of the N values for real and false noses. The Graph shows a significant separation between the two PDFs, which proves that the PRODIGY technique can distinguish most real noses from false noses.



Graph 1: PDF of N values

Calculations using the data used to create Graph 1 shows that about 2% of false noses have an N value of greater than -20. None of the real noses tested have an N value of less than -20 so the algorithm rejects noses with an N value of less than -20. There are about 100-200 false noses in any nose set. Because of the above rule the algorithm rejects most of them leaving only 2-4 false noses.

## 6 Experimental Results

Tests carried out on a separate 16 images from the ones used to design the algorithm showed how well the PRODIGY performed. By selecting the nose with the highest N value 15 out of the 16 cases (approximately 94%) gave a positive result, i.e. the PRODIGY method was performed on the nose set of the image, the real nose was the nose with the highest N value and the analysis resulted in a location of the nose, details of the five zones and the size of the nose. Negative results occurred when although the N value for the nose was high a spurious object in the image gave a higher value. This compares with the similar method used by Craw et al[7] to locate lips which had a success rate of 95% but with the following improvements :-

- The technique is scale independent. (Note: The

technique is scale independent with the images tested, which had noses that varied between 8 and 28 pixels long)

- The technique is independent of objects in the background.
- The technique is position independent.

The PRODIGY algorithm located faces on several images. The face, after being transformed and then scaled, took up the whole image. The pictures in figs 4 & 5 show the result of this process.

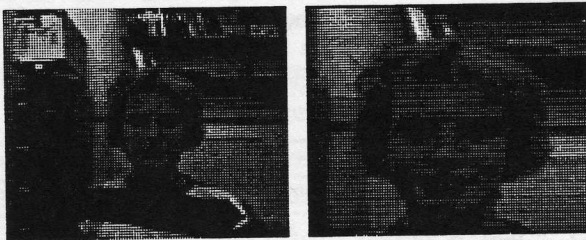


Figure 4: Before and after application of PRODIGY followed by zooming in on the face

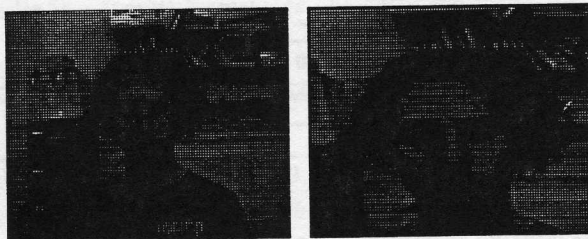


Figure 5: Before and after application of PRODIGY followed by zooming in on the face

## 7 Future work

The design of the PRODIGY assumed.

- All statistical values had normal distributions.
- All the zones were statistically independent.

These assumptions are not strictly correct and future work will attempt to analyse the effects of these and to improve the algorithm so that it does not make these assumptions.

The PRODIGY technique has a great dependency on the pre-processor and the zone locator. For faces not been tested the pre-processor designed may fail. It is desirable in the future to design a knowledge based technique to locate the zones around the object, using a larger database of faces.

The PRODIGY technique, although developed for faces that are pointing directly towards the camera, works with slightly rotated faces. Further development will result in techniques to locate rotated objects, either by introducing

extensions to the algorithm presented or using similar techniques alongside those described.

Adapting the PRODIGY technique for other facial features such as the eyes, mouth, eyebrows and ears will improve the solution to the face location problem. The combined results will produce one process to locate a face on an image with greater performance.

## 8 Conclusions

An extensive nose shape analysis algorithm has been designed based on the direction of intensity change on various sections of the nose. The PRODIGY technique is a knowledge based system using statistical data acquired from analysis of many noses in a face database. It is also independent of position, scale and of ambient lighting conditions. The technique is successful on 94% of the faces in an independent face bank. This show good performance but indicates a need for improvements. The algorithm successfully locates a nose on an image and describes its position, size and shape.

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