TECHNICAL REPORT

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Information technology — Automatic identification and data capture techniques — Direct Part Mark (DPM) Quality Guideline

Technologies de l'information — Techniques automatiques d'identification et de capture de données — Ligne directrice de qualité du marquage direct sur pièce (DPM)

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of the joint technical committee is to prepare International Standards. Draft International Standards adopted by the joint technical committee are circulated to national bodies for voting. Publication as an International Standard requires approval by at least 75 % of the national bodies casting a vote.

In exceptional circumstances, when the joint technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example) it may decide to publish a Technical Report. A Technical Report is entirely informative in nature and shall be subject to review every five years in the same manner as an International Standard.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO and IEC shall not be held responsible for identifying any or all such patent rights.

ISO/IEC TR 29158 was prepared jointly by Joint Technical Committee ISO/IEC JTC 1, *Information technology*, Subcommittee SC 31, *Automatic identification and data capture techniques*.

Introduction

Direct Part Marking (DPM) is a technology whereby, generally, an item is physically altered to produce two different surface conditions. This alteration can be accomplished by various means including, but not limited to, dot peen, laser, ink jet, and electro-chemical etch. The area of the alteration is called “the mark”. The area that includes the mark and background as a whole, when containing a pattern defined by a bar code symbology specification, is called “a symbol”.

When light illuminates a symbol, it reflects differently depending on whether it impinges on the background of the part or on the physical alteration. In most non-DPM bar code scanning environments, light is reflected off a smooth surface that has been coloured to produce two different diffuse reflected states. The DPM environment generally does not fit this model because the two different reflected states depend on at least one of the states having material oriented to the lighting such that the angle of incidence is equal to the angle of reflection. Sometimes the material so oriented produces a specular (mirror-like) reflectance that results in a signal that is orders of magnitude greater than the signal from diffuse reflectance.

In addition, from the scanner point-of-view, some marking and printing methods generate dots and are not capable of producing smooth lines.

Current specifications for matrix symbologies and two-dimensional print quality are not exactly suited to reading situations that have either specular reflection or unconnected dots or both. This is intended to act as a bridge between the existing specifications and the DPM environment in order to provide a standardized image-based measurement method for DPM that is predictive of scanner performance.

As with all symbology and quality standards, it is the responsibility of the applicator to define the appropriate parameters of this guideline for use in conjunction with a particular application.

Information technology — Automatic identification and data capture techniques — Direct Part Mark (DPM) Quality Guideline

1 Scope

This Technical Report is an engineering document intended for verifier manufacturers and application specification developers.

This Technical Report describes modifications which are to be considered in conjunction with the symbol quality methodology defined in ISO/IEC 15415 and a symbology specification. It defines alternative illumination conditions, some new terms and parameters, modifications to the measurement and grading of certain parameters, and the reporting of the grading results.

This Technical Report was developed to assess the symbol quality of direct marked parts, where the mark is applied directly to the surface of the item and the reading device is a two-dimensional imager.

When application specifications allow, this method may also be applied to symbols produced by other methods. This is appropriate when direct part marked (DPM) symbols and non-DPM symbols are being scanned in the same scanning environment. The symbol grade is reported as a DPM grade rather than as an ISO/IEC 15415 grade.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/IEC 15415, *Information technology — Automatic identification and data capture techniques — Bar code print quality test specification — Two-dimensional symbols*

ISO/IEC 15416, *Information technology — Automatic identification and data capture techniques — Bar code print quality test specification — Linear symbols*

ISO/IEC 19762-1, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 1: General terms relating to AIDC*

ISO/IEC 19762-2, *Information technology — Automatic identification and data capture (AIDC) techniques — Harmonized vocabulary — Part 2: Optically readable media (ORM)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC 15415, ISO/IEC 15416, ISO/IEC 19762-1, ISO/IEC 19762-2 and the following apply.

3.1
MLcal
mean of the light lobe from a histogram of the calibrated standard

3.2
MLtarget
mean of the light lobe from the final grid-point histogram of the symbol under test

3.3
reference symbol
high-contrast printed calibration card

EXAMPLE The GS1 Data Matrix calibrated conformance standard test card.

3.4
Rcal
reported reflectance value, Rmax, from a calibration standard

3.5
Rtarget
measured percent reflectance of the light elements of the symbol under test relative to the calibrated standard

3.6
SRcal
system response parameters (such as exposure and/or gain) used to create an image of the calibration standard

3.7
SRtarget
system response parameters (such as exposure and/or gain) used to create an image of the symbol under test

3.8
stick
line segment comprised of image pixels that is used to connect areas of the same colour that are near to each other

3.9
T1
threshold created using a histogram of the defined grey-scale pixel values in a circular area twenty times the aperture size in diameter, centred on the image centre using the algorithm defined in Annex A

3.10
T2
threshold created using the histogram of the reference grey-scale image pixel values at each intersection point of the grid using the method defined in Annex A

4 Abbreviated terms

CM Cell Modulation

CC Cell Contrast

FPD Fixed pattern damage

LED Light emitting diode

MD MeanDark

5 Overview of methodology

5.1 Process differences from 15415

All parameters in the symbology and print quality specifications apply except for:

- A different method for setting the image contrast.

- A different method for creating the binary image.

- A new method for choosing the aperture size.

- An image pre-process methodology for joining disconnected modules in a symbol.

- A different process for determining the Modulation and Reflectance Margin parameter renamed Cell Modulation.

- A different process for determining the Symbol Contrast parameter which has been renamed Cell Contrast.

- A difference process for computing Fixed Pattern Damage

- A new parameter called Minimum Reflectance.

This guideline explains how to both specify and report quality grades in a manner complementary to, yet distinct from, the method in ISO/IEC 15415.

5.2 Lighting

This guideline recommends three specific lighting environments consisting of two forms of diffuse lighting (non-directional):

- diffuse on-axis illumination uses a diffuse light source illuminating the symbol nominally perpendicular to its surface (nominally parallel to the optical axis of the camera).

- diffuse off-axis illumination uses light from an array of LEDs reflected from the inside of a diffusely reflecting surface of a hemisphere, with the symbol at its centre, to provide even incident illumination from all directions.

- Directional illumination is oriented at a low angle (approximately 30 degrees) to the mark surface.

6 Obtaining the image

6.1 Orientation of the symbol to the camera

6.1.1 Camera position

The camera is positioned such that the plane of the image sensor is parallel to the plane of the symbol area.

6.1.2 Orienting the symbol

The part is placed such that the symbol is in the centre of the field of view and oriented so that the horizontal lines in the symbol are parallel with a line formed by the edge of the image sensor to within +/- 5 degrees.

6.2 Lighting

Two lighting environments each with sub-options are defined in this document. The defined lighting environments are denoted in the reported grade using the format defined in ISO/IEC 15415 using the angle specifier with a combination of numbers and letters as defined below.

Note: This does not limit the prerogative of an Application Specification to choose different lighting environments based on application requirements. Alternate lighting environments should include specifiers consistent with the format of those below which can be used for communicating quality requirements and quality grades.

6.2.1 Diffuse perpendicular (on-axis/bright field) (90)

A flat diffusing material is oriented such that the plane of the material is parallel to the plane of the symbol area. The symbol is uniformly illuminated with diffuse light incident at 90 +/- 15 degrees relative to the optical axis to the plane of the symbol. The angle specifier shall be 90 to denote this lighting environment.

6.2.2 Diffuse off-axis (D)

A diffusely reflecting dome is illuminated from below so that the reflected light falls non-directionally on the part and does not cast defined shadows. This is commonly used for reading curved parts. The angle specifier shall be D.

6.2.3 Low angle, four direction (30Q)

Light is aimed at the part at an angle of 30 +/- 3 degrees from the plane of the surface of the symbol from four sides such that the lines describing the centre of the beams from opposing pairs of lights are co-planar and the planes at right angles to each other. One lighting plane is aligned to be parallel to the line formed by a horizontal edge of the image sensor to within +/- 5 degrees. The lighting shall illuminate the entire symbol area with uniform energy. The angle specifier shall be 30Q.

6.2.4 Low angle, two direction (30T)

Light is aimed at the part at an angle of 30 +/- 3 degrees from two sides. The light may be incident from either of the two possible orientations with respect to the symbol. The lighting plane is aligned to be parallel to the line formed by one edge of the image sensor to within +/- 5 degrees. The lighting shall illuminate the entire symbol area with uniform energy. The angle specifier shall be 30T.

6.2.5 Low angle, one direction (30S)

Light is aimed at the part at an angle of 30 +/- 3 degrees from one side. The light may be incident from any of the four possible orientations with respect to the symbol. The plane perpendicular to the symbol surface containing the centre of the beam is aligned to be parallel to the line formed by one edge of the image sensor to within +/- 5 degrees. The lighting shall illuminate the entire symbol area with uniform energy. The angle specifier shall be 30S.

6.3 Image focus

The camera is adjusted such that the symbol is in best focus.

6.4 Reflectance calibration

Using a high-contrast, nationally traceable printed calibration card (such as the GS1 Data Matrix calibrated conformance standard test card) calibrated using a known aperture, take an image of the calibration card. Using the known aperture size, sample the centre of every element in the image, not including the outer spaces, and pick the highest reflectance of the target.

Set the system response so that the mean of the light elements is in the range of 70% to 86% of the maximum grey scale (MLcal) and the black level (no light) is nominally equal to zero. The system response is the linear relationship between the reflectivity of the target and the pixel intensity values in the image as a result of several factors (e.g. shutter speed, imager sensitivity, f-stop, gain, illumination intensity.) This procedure requires the ability to adjust at least one of these factors in order to adjust the system response.

Record the system response as the Reference System Response (SRcal) and record MLcal.

6.5 Initial image reflectance level of the symbol under test

6.5.1 Initialize aperture size

Set the aperture to 0.8 of the minimum X-dimension of the application, and apply it to the original image to create a reference greyscale image.

6.5.2 Create initial histogram of symbol under test

Create a histogram of the reference grey-scale pixel values in a circular area 20 times the aperture size in diameter, centred on the image centre, and find the Threshold, T1, using the algorithm defined in Annex A.

The threshold divides the histogram into two portions: a portion less than the threshold which contains dark pixels and a portion greater than the threshold which contains light pixels (called the “light lobe”).

6.5.3 Compute mean

Compute the mean of the light lobe.

6.5.4 Optimize image

Adjust the system response by taking new images and repeating steps 6.5.1 and 6.5.2 until the mean of the light elements is in the range of 70% to 86% of the maximum grey scale.

7 Obtaining the test image

The referenced matrix symbologies all require the locating of continuous modules in their reference decode algorithms. Some marking technologies are not capable of producing symbols with smooth, continuous lines when viewed by an imager. For example, dot peened symbols often produce unconnected dots. This section includes a method of pre-processing the image that will connect disconnected modules so that the standard reference decode algorithms can operate successfully.

Once the grid of the symbol is determined, the location information is transferred to the evaluation of the reference greyscale image and subsequent processing occurs using the reference greyscale image.

7.1 Binarize image

Compute a reference greyscale image using the current aperture size. Using T1, binarize the entire image.

7.2 Apply Reference Decode Algorithm

Attempt to find and process the symbol using the symbology Reference Decode Algorithm and the current aperture size. If the attempt fails, go to 7.3. If successful go to 7.4.

Note: where a symbology has a reference decode algorithm that operates successfully on nominally disconnected modules (e.g. “dot” codes) the process of connecting modules is inappropriate. With these symbologies, if the application of the Reference Decode Algorithm fails then go to 7.3.4 (not 7.3).

7.3 Connect areas of the same colour

This process is called the "stick function" and operates on the binarized image. The output is used for the initial decode using the reference decode algorithm. The steps below seek to connect areas in the image that are separated by less than one module, while not connecting areas which are separated by a distance of a module or more, for example alternating "clock teeth" modules.

7.3.1 Initializing stick size and module colour

Since a module size is not known during the execution of this algorithm, successively larger distance guesses are used within a range from the size of 50% of the smallest X-dimension to 110% of the largest X-dimension allowed by the application specification.

In addition, knowledge of the colour of “on” versus “off” modules is also required by the algorithm. Generally the “on” colour is dark for bright field illumination and light for dark field illumination. (For instance, the "on" colour is the colour of the “L” pattern of a Data Matrix symbol.) If a verifier does not “know” the colour of "on", the algorithm may need to be repeated for each case.

Note: Implementers are free to optimize this algorithm (such as by attempting a better first guess of the correct stick size by analyzing the image), as long as the equivalent result is obtained.

7.3.2 Connect like colours

1. Prepare by:

   a) Setting every pixel in the output image to the background (off) colour.
   b) Selecting an initial stick size equal to 50% of the minimum X of the application.

2. Starting on the row of the image one half-stick length down from the top, and the column one half-stick length in from the left:

   a) If the colour of the pixel is the “on” colour, set the pixel in the same position in the output image to the “on” colour, and continue at step 2e.
   b) Find the two pixels which are one-half stick distance to the left and one-half the stick distance to the right and the two pixels that are one-half stick distance above and below.
   c) If both of the horizontal or vertical pixels found in step 2b are the “on” colour, then go to step 2d else continue to step 2e.
   d) For each pixel on the line or lines between the two "on" pixels found in step 2b (a line equal in length to the stick), set the correspondingly positioned pixels in the output image to the “on” colour.
   e) Move to the next pixel and go to step 2a. (If the position of the current pixel is one half-stick length in from the right, the next pixel is at the start of the column one half-stick length in from the left of the next row. If the position of the current pixel is on the row one half stick length up from the bottom, and one half stick length in from the right, exit since the image is completely processed.)

7.3.3 Apply the Reference Decode Algorithm

The referenced matrix symbologies all require the locating of continuous modules in their reference decode algorithms. Some marking technologies are not capable of producing symbols with smooth, continuous lines when viewed by an imager. For example, dot peened symbols often produce unconnected dots.

Once the primary lines of the symbol are determined, the location information is transferred to the evaluation of the original image and subsequent processing occurs using the original image.

Using the connected image from 7.3.2, find the symbology reference lines with the symbology reference decode algorithm. Note: for example, the symbology reference lines for Data Matrix comprise the "L."

Transfer the reference lines to the original binarized image. Perform the rest of the reference decode algorithm. If successful, go to 7.4.

7.3.4 Repeat if necessary

If the decode attempt fails, choose a new stick size that is at least one pixel more in length and a new aperture size equal to 0.8 stick size and go to 7.1.

7.3.5 Continue until end

Continue until the symbol is successfully decoded or the stick size exceeds the maximum stick size or one-tenth of the maximum image dimension in pixels (if the maximum X-dimension is not known). If the lines are not found, the symbol grade is Zero.

Note: This algorithm assumes that the symbol is oriented orthogonal to the image sensor, so that modules that must be connected are aligned vertically and horizontally in the image. If this were not true, the stick would need to be rotated through all angles, in addition to the vertical and horizontal directions.

7.4 Final image adjustment

This procedure uses only the nominal centres of modules to create a highly bi-modal histogram of the symbol reflectance states.

7.4.1 Determine grid-point reflectance with two apertures

Re-compute the reference grey-scale image using two new aperture sizes equal to 0.5 and 0.8 of the measured average grid spacing. Perform the following calculations and grading for both apertures.

7.4.2 Create a grid-point histogram

Create a histogram of the reference grey-scale image pixel values at each intersection point of the grid determined from the decode and find T2 using the algorithm defined in Annex A.

7.4.3 Measure MeanLight

Measure the MeanLight of the grid-centre point histogram. If it is in the range of 70% to 86% of the maximum grey scale then retain the values for MeanDark (MD) and MeanLight.

If not, adjust the system response and go to 7.4.1

7.4.4 Record parameters

Set MLtarget equal to MeanLight. Record the system response as SRtarget. Record the new T2.

7.4.5 Create binarized images for the Symbology Reference Decode

If the decode was achieved using the Stick Function then set the stick size to the average grid spacing and apply the stick algorithm using T2 on the new reference grey-scale image to create the final binarized image. Otherwise, binarize using T2.

7.4.6 Decode

Decode the final binary image using the steps of 7.3.3 through 7.4.5 using the symbology Reference Decode Algorithm. Recalculate T2 using the grid centres of this decode. If this decode fails, apply the stick algorithm in 7.4.5 and decode again.

8 Determine contrast parameters

Calculate the following parameters using the T2 value and grid centres of 7.4.6.

8.1 Calculate Cell Contrast (CC)

Calculate CC using the following equation, referencing the algorithm found in Annex A:

CC = (MLtarget – MD) / MLtarget

8.2 Calculate Cell Modulation (CM)

Calculate CM using the following equation:

If (R < T2) then CM = (T2 - R) / (T2 - MD) Else CM = (R - T2) / (MLtarget - T2)

Where R is the measured reflectance of the cell.

8.3 Calculate % Reflectance of Symbol (Rtarget)

Rtarget = Rcal x (SRcal/SRtarget) x (MLtarget/MLcal)

9 Grading

9.1 Cell Contrast (CC)

Table 1 — Grading of Cell Contrast

CC	Grade
≥ 30%	4
≥ 25%	3
≥ 20%	2
≥ 15%	1
< 15%	0

Note: With an 8-bit grey-scale sensor, 15% is equal to a difference of 30 grey scale values.

9.2 Minimum Reflectance

Table 2 — Grading of Minimum Reflectance

Rtarget	Grade
≥ 5%	4
< 5%	0

Note: this limits the ratio of SRtarget/SRcal to approximately 16.

9.3 Cell Modulation (CM)

Replace Modulation and Reflectance Margin in 15415 with CM, using the new calculation for threshold and formula for CM and reduce the number of notional UEC levels to 4, 3, and 0 (A, B, and F), where the grade level of 3 now spans 1 to 3. The grade for Cell Modulation uses the same grading scale as Modulation in ISO/IEC 15415.

9.4 Fixed pattern damage

Calculate fixed pattern damage as described in ISO/IEC 15415 and the symbology specifications except:

- Use the threshold, T2, for the modulation overlay and
- When determining the average grade of the segments, use the average of the notional damage grade at the D grade level.
- Rename average grade as "distributed damage grade".

9.5 Final grade

Select the aperture size that generated the better of the two grades in the parameters above and use the associated image and parameters for the remainder of the grading calculations from 15415. If the two grades are identical and only one resulted in a decode, use the one that decoded. If both decoded, use the image and parameters associated with the aperture size of 0.8 X.

10 Communicating grade requirements and results

This section discusses the method of signalling grading requirements to the maker of the mark and for reporting the resulting grade to the customer. Depending on the requirements of the application specification, one or more grades for each part may be required. See Annex B.

10.1 Communication from Application to Verifier

The application shall specify a range of X-dimensions taking into consideration that large X-dimensions will facilitate greater surface texture. For example, for an application that has a range of X of 10 to 20 mils, the grade requirement is communicated as /10-20/ in place of the aperture size.

10.2 Communicating from Verifier to Application

Grades reported according to this guideline shall be prefaced with "DPM". With the preface of "DPM", the grade, aperture size and light colour are reported in the same way as defined in ISO/IEC 15415, however lighting angle and orientation are communicated as follows.

10.3 Communicating Lighting

10.3.1 Low angle lighting

Depending on the surface texture and other parameters, each orientation may give a different grade than the others.

Low-angle lighting orientation is described with the angle as "30T" (representing the grade obtained with illumination from two sides in the same plane), "30Q" (representing the grade obtained with illumination from four sides) or "30S" (representing the grade obtained with illumination from one side).

Note: generally, "30S" is used where it is not possible to have lighting from two sides.

10.3.2 High-angle lighting

Non-directional diffuse off-axis lighting is referenced as "D" and diffuse on-axis (near-perpendicular) lighting as "90".

10.3.3 Lighting orientation grade

Lighting orientation is reported as the single orientation that was used to determine the grade. If the requirement is for more than one lighting setup, then the grade should be reported for each setup.

10.3.4 Lighting angle grade

Lighting angle is specified using the separator "|" to designate "or" and the separator "&" to designate "and". For example,

"30Q" or "90" = (30Q|90)

"30Q" and "90" = (30Q&90)

Lighting angle is reported as the single angle that was used to determine the grade. If the requirement is for more that one angle, then at least the lowest grade shall be reported or optionally one grade reported for each angle.

10.4 Communicating the use of a proprietary decode

When a proprietary decode is used, the rest of the metrics shall follow the requirements of this document.

When a proprietary decode is used, it shall be clearly reported in the grade report. For example, the verifier shall report a grade of 0 (zero) for decode and may report the other measurements of this guideline.

When a proprietary decode is allowed, it shall be clearly stated in the application specification.

Note: when a proprietary decode is used, the sampling points for the remaining metrics may differ from verifier to verifier.

Annex A
(normative)

Threshold determination method

A.1 Algorithm description

Start by creating a histogram of the defined grey-scale values in the defined region and proceeds as follows:

1. Initialize the variable minVariance to a very large number and initialize Tmin and Tmax to zero.

2. For every grey-scale value, "t", starting from the lowest grey-scale value to the highest grey-scale value (0 to 255 for an 8-bit image sensor),

a. Compute the mean and variance of pixels below t and call it MeanDark and VarianceDark

b. Compute the mean and variance of pixels above or equal to t and call it MeanLight and VarianceLight

c. Compute Variance = VarianceLight + VarianceDark.

d. If Variance < minVariance, save Variance in minVariance and save t in Tmin

e. If Variance = minVariance save t in Tmax.

Note: The step e is used to break ties. Tmin is the smallest grey-level where the variance is the minimum and Tmax is the largest grey-level where the variance is the same minimum.

3. Optimal threshold T = (Tmin + Tmax) / 2.

A.2 Example

For simplicity, an image with only 100 pixels (a 10 x 10 image) will be used. Additionally, for the purpose of the example, the image is composed of 4 bit pixels (16 grey levels). The sample image is shown in Figure A.1, where each pixel is magnified so that individual pixels can be discerned.

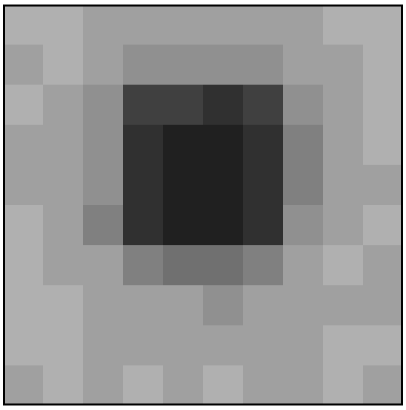

Figure A.1 — Image used in this example.

We begin by counting how many pixels are contained in the image with each of the 16 grey levels. The result of this count is shown in Table A.1, and is plotted as a histogram in Figure A.2.

Table A.1 — Count of grey level occurrences

Gray Level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3
5	0
6	0
7	2
8	5
9	10
10	44
11	23
12	0
13	0
14	0
15	0

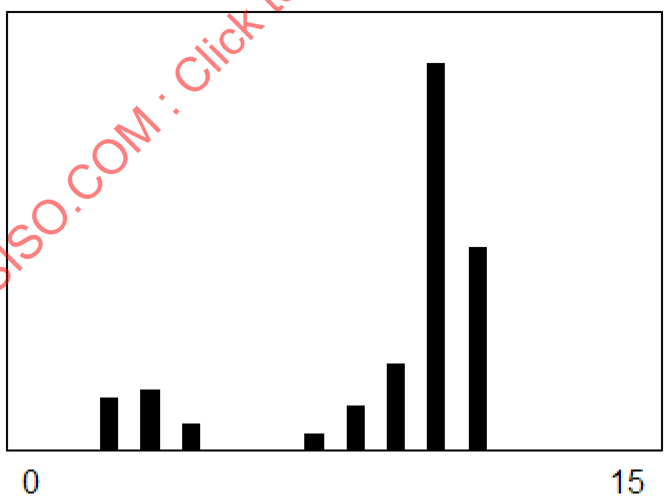

Figure A.2 — Histogram of the data from Table A.1

For each possible threshold, we separate the histogram into two portions – one for the dark elements and one for the light elements. The first possible threshold is between 0 and 1, the next is between 1 and 2, and so on. For each possible threshold, compute the variance of both portions of the histogram.

For example, for the possible threshold between 4 and 5, the dark element histogram contains the grey levels 0, 1, 2, 3 and 4 as shown in Table A.2.

Table A.2 — Dark pixel portion for threshold of 4.5

Gray Level	Number of pixels with grey level
0	0
1	0
2	6
3	7
4	3

The variance of this distribution is calculated as follows:

The mean is ((2 × 6) + (3 × 7) + (4 × 3)) ÷ 16 = 2.81, which can be described as the weighted average of Table A.2.

The variance is $(([2.81-2]^2 \times 6) + ([2.81-3]^2 \times 7) + ([2.81-4]^2 \times 3)) \div 16 = .53$

Similarly, the variance of the light elements (those whose pixel value is 5 or greater) is 0.84.

In likewise fashion, the variances of the dark and light portions of the histogram for each threshold can be computed. The results are shown in Table A.3

Table A.3 List of variances for all possible thresholds

Threshold	Variance of Dark Elements	Variance of Light Elements	Sum of Variances
0.5	0.00	7.67	7.67
1.5	0.00	7.67	7.67
2.5	0.00	5.00	5.00
3.5	0.25	2.00	2.25
4.5	0.53	0.84	1.37
5.5	0.53	0.84	1.37
6.5	0.53	0.84	1.37
7.5	2.20	0.65	2.85
8.5	5.52	0.40	5.92
9.5	8.50	0.23	8.73
10.5	8.11	0.00	8.11
11.5	7.67	0.00	7.67
12.5	7.67	0.00	7.67
13.5	7.67	0.00	7.67
14.5	7.67	0.00	7.67
15.5	7.67	0.00	7.67

An optimum threshold is chosen such that the sum of variances of both portions of the histogram is minimized. As can be seen from Table A.3, the minimum of the sum of variances is which occurs at thresholds: 4.5, 5.5, and 6.5. There is a range of thresholds that all give this minimum variance. In this case take the average of the lowest and highest threshold which gives this minimum which is 5.5 in this example.

Note that the threshold obtained by this averaging will not necessarily have the same minimum sum of variances as it does in this example. If there is a single threshold which gives the minimum sum of variances, then take that threshold. This chosen threshold is considered the “optimum” threshold as determined by the algorithm in A.1, because it results in two separate portions of the overall histogram which are assumed to be most representative of two groups of elements (dark and light). Note: the portion of the histogram to the right of the threshold is called the “light lobe”.

When the image is binarized using the calculated threshold, the result is shown in Figure A.3. See Figure A.3.

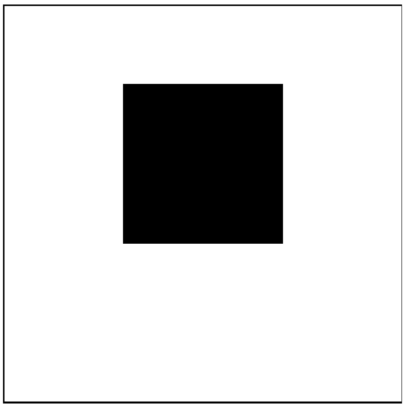

Figure A.3 — Image with threshold applied.