A note on minor errors in the International QR Barcode standard *ISO/IEC 18004:2000(E)*

Johan Persson
Aditus Consulting, Sweden
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email: johanp@aditus.nu

Abstract

In this note we describe why the encoding example shown in Annex G of the QR barcode international standard [1] has chosen an incorrect XOR mask in the final step of the encodation process.

Annex G in the standard uses the optical XOR mask identified by index 3 (011) but we claim that the mask with index 7 (111) gives an overall lower penalty score according to the rules set out in the standard in section 8.8.1. This note details and motivates our claim.

We also point out one further minor error and one omission in the standard in the two concluding appendices to this note.

(15 pages)

1 Introduction

In the final step of the creation of the matrix representing the 2-dimensional QR barcode the standard specifies that a suitable XOR mask should be applied to the matrix representing the QR barcode in order to secure good optical conditions for the barcode reader/scanner.

It should be noted that the selection of this mask (which is applied to the bit matrix with a XOR operation) is somewhat arbitrary. The purpose of this XOR mask at the end of the encoding process is to make the overall distribution of black and white areas as even as possible given the encoded data. This will then serve to reduce the risk for faulty readings by scanners by maximizing the optical information in the matrix (achieving high frequency content). The QR standard specifies that 8 different masks (defined in section 8.8.1 in the standard) should be considered.

Since the information about what mask is chosen is encoded in the barcode unaffected by the chosen mask, (since it is part of the functional patterns which are excluded from the mask operation), a QR reader will always have information on what mask has been chosen and can therefore retrieve the original bit pattern. Hence, the actual selection of the mask is not absolutely critical since several masks can give similar optical performance. The standard specifies a method to evaluate each mask in turn by calculating a penalty score. The mask with the lowest penalty score should then be chosen.

In the following discussion we will assume that the reader has basic technical knowledge of the structure of the QR code and is familiar with the encodation procedure. The discussion will be restricted to comparing the final application of the mask once the encodation of data and bit placement in the matrix has been done according to the rules of the QR barcode.

The data used in this note is the same as is used in Annex G, a string consisting of 8 numeric values, ”01234567”, encoded using numerical encodation schema and QR version 1-M for the layout and error correction level.

2 Applying mask 3 and 7 to the original bit placement

The result after applying mask with index 3 and 7 to the matrix corresponding to the data '01234567' (as used in Annex G in [1]) is shown in Figure 1 ('-' corresponds to a binary 0 and 'X' corresponds to a binary 1 in the textual representation of the matrix). For easier visual reference to the individual modules in the

matrix a row and column of numbers have been added to the top and to the left of the textual representation.

In Figure 2 graphical versions of the barcodes are shown (using a module size of 6 pixels). However, for the purpose of this note the textual representation is easier to read and follow and is the representation that will be used in the rest of this note.

Applying mask index = 3 (score=1052)

```
 012345678901234567890
0XXXXXXX-XX-XX-XXXXXXX
1X-----X-X-X---X-----X
2X-XXX-X--XX-X-X-XXX-X
3X-XXX-X-XX----X-XXX-X
4X-XXX-X--XX---X-XXX-X
5X----X--XX---X-----X
6XXXXXXX-X-X-X-XXXXXXX
7--------XX-----------
8X-XX-XXX--X---X--X-XX
9---X-X-XX-X-X--X-XX--
0X--X-XXXX---XXXXX--X-
1XX-X--X--X-XX---X-X-
2---XXXXXX--X-X--X----
3-----X--XXX--X-X----X
4XXXXXXX-X----XX-X-XX-
5X-----X-X-XXXXX---X-X
6X-XXX-X--X-X--X-----X
7X-XXX-X-X-X--X--X-XX-
8X-XXX-X-X-XX-X--X-X--
9X-----X--X-XX-X-XX-XX
0XXXXXXX-X--XX--X---X-
```

Applying mask index = 7 (score=1022)

```
 012345678901234567890
0XXXXXXX---XXX-XXXXXXX
1X-----X--X----X-----X
2X-XXX-X--XXX--X-XXX-X
3X-XXX-X--X-XX-X-XXX-X
4X-XXX-X--XXXX-X-XXX-X
5X-----X-X-----X-----X
6XXXXXXX-X-X-X-XXXXXXX
7----------X----------
8X--X-XX-X-XXXX-X-----
9XX-X----X-XX-X-X---X-
0-X-X--X-X--X--XXXXX--
1XXX-X--XXX--XXXXXX-XX
2--X--XXX-XXX-XXX----X
3--------X----XX-X----
4XXXXXXX----XX-X-XX---
5X-----X-X-X---X--X-XX
6X-XXX-X--X--XXX--XXXX
7X-XXX-X-XX---XXX--XXX
8X-XXX-X--X-X-XXX--X-X
9X-----X---XXX--X-X-X-
0XXXXXXX-X----X-X-XX--
```

Figure 1: *Applying masks 3 and 7 to the bit placement matrix corresponding to data = '01234567'. See section 2.5 for an explanation of the highlighted pattern.*

QR 1-M Code for Data='01234567', mask = 3 (penalty score = 1052)

QR 1-M Code for Data='01234567', mask = 7 (penalty score = 1022)

Figure 2: *QR barcode versions for data '01234567' using both mask 3 and mask 7*

In the following sections we will do a detailed walk through of the evaluation of the penalty points for both these masks and show why we claim mask 7 should be used with this particular data string. The penalty score evaluation is made in accordance with section 8.8.2 in the standard.

As we discuss in section 3 the standard leaves some room for interpretation on the details on how to

perform these evaluations. Where there is room for interpretation we state our interpretation.

In all the calculations the left column of the figures corresponds to mask 3 and the right column to mask 7 score calculations.

As a final side note we make the observation that visually mask 3 is subjectively more appealing for most human observers since it avoids the concentration of black blocks that is slightly more apparent when using mask 7 as can be seen in figure 2 above. This concentration is also reflected in the higher penalty score for blocks when using mask 7 (see section 2.3).

2.1 Principles of penalty score evaluation

The overall penalty score evaluation is based on 4 different steps that are described in the standard and paraphrased below

1. the number of vertical or horizontal lines (≥ 5 modules in length) of the same color (black/white)
2. the number of blocks (≥ 2x2 modules in size) of the same color (black/white)
3. the number of 11311 patterns (finder patterns, black-white-black-black-black-white-black)
4. the overall proportion of black and white modules

The standard specifies that the entire matrix (including functional patterns) shall be considered in the score calculation. The following 4 sections details each of the above steps for the matrices shown in Figure 1.

2.2 Identifying vertical and horizontal lines of same color

When it comes to **vertical and horizontal lines of same colors** of length ≥ 5 we have the following result (we don't give a visual version of these findings – they are trivial). Table 24 in the standard stipulates that the scoring shall be calculated as *3+(len-5). T*he accumulated score per horizontal/vertical found pattern is stated below.

```
SUMMARY Score = 187

"BLACK LINES"
 Vertical at (0,0)  len=7 (Acc score=5)
 Vertical at (14,0) len=7 (Acc score=10)
 Vertical at (8,3)  len=5 (Acc score=13)
 Vertical at (0,6)  len=7 (Acc score=18)
 Vertical at (14,6) len=7 (Acc score=23)
 Vertical at (8,7)  len=5 (Acc score=26)
 Vertical at (10,13)len=6 (Acc score=30)
 Vertical at (0,14) len=7 (Acc score=35)
 Vertical at (0,20) len=7 (Acc score=40)

 Horizontal at (0,0)  len=7 (Acc score=5)
 Horizontal at (0,14) len=7 (Acc score=10)
 Horizontal at (6,0)  len=7 (Acc score=15)
 Horizontal at (6,14) len=7 (Acc score=20)
 Horizontal at (10,12)len=5 (Acc score=23)
 Horizontal at (12,3) len=6 (Acc score=27)
 Horizontal at (14,0) len=7 (Acc score=32)
 Horizontal at (15,10)len=5 (Acc score=35)
 Horizontal at (20,0) len=7 (Acc score=40)

"WHITE LINES"
 Vertical at (1,1)  len=5 (Acc score=3)
 Vertical at (15,1) len=5 (Acc score=6)
 Vertical at (9,2)  len=5 (Acc score=9)
 Vertical at (7,4)  len=5 (Acc score=12)
 Vertical at (1,5)  len=5 (Acc score=15)
 Vertical at (15,5) len=5 (Acc score=18)
 Vertical at (0,7)  len=8 (Acc score=24)
 Vertical at (13,7) len=8 (Acc score=30)
 Vertical at (8,9)  len=5 (Acc score=33)
 Vertical at (1,11) len=11 (Acc score=42)
 Vertical at (0,13) len=10 (Acc score=50)
 Vertical at (1,15) len=5 (Acc score=53)
 Vertical at (14,15)len=6 (Acc score=57)
 Vertical at (12,17)len=7 (Acc score=62)
 Vertical at (1,19) len=5 (Acc score=65)

 Horizontal at (1,1)  len=5 (Acc score=3)
 Horizontal at (1,15) len=5 (Acc score=6)
 Horizontal at (5,1)  len=5 (Acc score=9)
 Horizontal at (5,15) len=5 (Acc score=12)
 Horizontal at (7,0)  len=8 (Acc score=18)
 Horizontal at (7,10) len=11 (Acc score=27)
 Horizontal at (13,0) len=8 (Acc score=33)
 Horizontal at (15,1) len=5 (Acc score=36)
 Horizontal at (16,15)len=5 (Acc score=39)
 Horizontal at (19,1) len=5 (Acc score=42)
```

```
SUMMARY Score = 176

"BLACK LINES"
 Vertical at (0,0)  len=7 (Acc score=5)
 Vertical at (14,0) len=7 (Acc score=10)
 Vertical at (0,6)  len=7 (Acc score=15)
 Vertical at (14,6) len=7 (Acc score=20)
 Vertical at (0,14) len=7 (Acc score=25)
 Vertical at (10,14)len=9 (Acc score=32)
 Vertical at (8,15) len=5 (Acc score=35)
 Vertical at (0,20) len=7 (Acc score=40)

 Horizontal at (0,0)  len=7 (Acc score=5)
 Horizontal at (0,14) len=7 (Acc score=10)
 Horizontal at (6,0)  len=7 (Acc score=15)
 Horizontal at (6,14) len=7 (Acc score=20)
 Horizontal at (10,14)len=5 (Acc score=23)
 Horizontal at (11,12)len=6 (Acc score=27)
 Horizontal at (14,0) len=7 (Acc score=32)
 Horizontal at (20,0) len=7 (Acc score=37)

"WHITE LINES"
 Vertical at (1,1)  len=5 (Acc score=3)
 Vertical at (15,1) len=5 (Acc score=6)
 Vertical at (1,5)  len=5 (Acc score=9)
 Vertical at (15,5) len=5 (Acc score=12)
 Vertical at (0,7)  len=11 (Acc score=21)
 Vertical at (13,7) len=8 (Acc score=27)
 Vertical at (0,8)  len=5 (Acc score=30)
 Vertical at (5,9)  len=6 (Acc score=34)
 Vertical at (0,13) len=8 (Acc score=40)
 Vertical at (1,15) len=5 (Acc score=43)
 Vertical at (15,16)len=6 (Acc score=47)
 Vertical at (11,18)len=5 (Acc score=50)
 Vertical at (1,19) len=5 (Acc score=53)

 Horizontal at (1,1)  len=5 (Acc score=3)
 Horizontal at (1,15) len=5 (Acc score=6)
 Horizontal at (5,1)  len=5 (Acc score=9)
 Horizontal at (5,9)  len=5 (Acc score=12)
 Horizontal at (5,15) len=5 (Acc score=15)
 Horizontal at (7,0)  len=10 (Acc score=23)
 Horizontal at (7,11) len=10 (Acc score=31)
 Horizontal at (8,16) len=5 (Acc score=34)
 Horizontal at (13,0) len=8 (Acc score=40)
 Horizontal at (15,1) len=5 (Acc score=43)
 Horizontal at (19,1) len=5 (Acc score=46)
```

2.3 Identifying blocks of same color

For **blocks of the same color** (defined as areas ≥ 2x2 with the same color) we get the following evaluation. In the standard it is undefined if priority is given to find wide or tall blocks – in this evaluation we prioritize wide over tall. See discussion in section 3.1 for what potential impact this might have on the penalty scoring. In the evaluation below we have also given a visual version of what blocks are found for ease of reference.

```
SUMMARY Score = 105

"BLACK BLOCKS"
 block at (2,2)  of size (3 x 3) (Acc score:12)
 block at (2,16) of size (3 x 3) (Acc score:24)
 block at (4,9)  of size (2 x 2) (Acc score:27)
 block at (9,7)  of size (2 x 2) (Acc score:30)
 block at (10,12)of size (2 x 2) (Acc score:33)
 block at (14,13)of size (2 x 2) (Acc score:36)
 block at (16,2) of size (3 x 3) (Acc score:48)
 block at (19,11)of size (2 x 2) (Acc score:51)


"WHITE BLOCKS"
 block at (3,11)  of size (3 x 3) (Acc score:12)
 block at (4,7)   of size (2 x 2) (Acc score:15)
 block at (7,11)  of size (2 x 3) (Acc score:21)
 block at (7,15)  of size (2 x 2) (Acc score:24)
 block at (9,1)   of size (2 x 2) (Acc score:27)
 block at (11,14) of size (2 x 2) (Acc score:30)
 block at (12,0)  of size (2 x 3) (Acc score:36)
 block at (12,17) of size (2 x 3) (Acc score:42)
 block at (13,11) of size (2 x 2) (Acc score:45)
 block at (15,15) of size (2 x 3) (Acc score:51)
 block at (17,14) of size (2 x 2) (Acc score:54)



 01234567890123456789
0XXXXXXX-XX-XX-XXXXXXX
1X-----X-X-X---X-----X
2X-XXX-X--XX-X-X-XXX-X
3X-XXX-X-XX-----X-XXX-X
4X-XXX-X--XX---X-XXX-X
5X-----X--XX---X-----X
6XXXXXXX-X-X-X-XXXXXXX
7--------XX-----------
8X-XX-XXX--X---X--X-XX
9---X-X-XX-X-X--X-XX--
0X--X-XXXX---XXXXX--X-
1XX-X---X--X-XX--X-X-
2---XXXXXX--X-X--X----
3---------XXX--X-X---X
4XXXXXXX-X-----XX-X-XX-
5X-----X-X-XXXXX---X-X
6X-XXX-X--X-X--X-----X
7X-XXX-X-X-X--X--X-XX-
8X-XXX-X-X-XX-X--X-X--
9X-----X--X-XX-X-XX-XX
0XXXXXXX-X--XX--X---X-
```

```
SUMMARY Score = 126

"BLACK BLOCKS"
 block at (2,2)  of size (3 x 3) (Acc score:12)
 block at (2,16) of size (3 x 3) (Acc score:24)
 block at (3,11) of size (2 x 2) (Acc score:27)
 block at (8,10) of size (2 x 2) (Acc score:30)
 block at (10,14)of size (2 x 4) (Acc score:39)
 block at (12,13)of size (2 x 2) (Acc score:42)
 block at (15,19)of size (3 x 2) (Acc score:48)
 block at (16,2) of size (3 x 3) (Acc score:60)
 block at (16,13)of size (3 x 2) (Acc score:66)

"WHITE BLOCKS"
 block at (0,7)  of size (5 x 2) (Acc score:12)
 block at (1,12) of size (2 x 2) (Acc score:15)
 block at (7,1)  of size (2 x 2) (Acc score:18)
 block at (7,16) of size (2 x 5) (Acc score:30)
 block at (9,4)  of size (2 x 2) (Acc score:33)
 block at (12,0) of size (2 x 2) (Acc score:36)
 block at (12,3) of size (2 x 2) (Acc score:39)
 block at (12,17)of size (2 x 3) (Acc score:45)
 block at (13,9) of size (2 x 2) (Acc score:48)
 block at (15,15)of size (2 x 2) (Acc score:51)
 block at (16,10)of size (2 x 2) (Acc score:54)
 block at (17,16)of size (2 x 2) (Acc score:57)
 block at (18,7) of size (2 x 2) (Acc score:60)


 01234567890123456789
0XXXXXXX---XXX-XXXXXXX
1X-----X--X---X-----X
2X-XXX-X--XXX--X-XXX-X
3X-XXX-X--X-XX-X-XXX-X
4X-XXX-X--XXXX-X-XXX-X
5X-----X-X-----X-----X
6XXXXXXX-X-X-X-XXXXXXX
7-------------X-------
8X--X-XX-X-XXXX-X-----
9XX-X---X-XX-X-X---X-
0-X-X--X-X--X--XXXXX--
1XXX-X--XXX--XXXXX-XX
2--X--XXX-XXX-XXX----X
3-------X-----XX-X----
4XXXXXXX-----XX-X-XX---
5X-----X-X-X---X--X-XX
6X-XXX-X--X--XXX--XXXX
7X-XXX-X-XX---XXX--XXX
8X-XXX-X--X-X-XXX--X-X
9X-----X---XXX--X-X-X-
0XXXXXXX-X----X-X-XX--
```

2.4 Proportion of white/black dots

For evaluation the **proportion of colors** both masks yields a score of 0 penalty points since the mix is so even (49% black dots for index = 3 and 50% black dots for index=7).

2.5 Identifying 11311 patterns

We now come to one of the more ambiguous patterns to detect, the finder pattern. It is not that it is technically difficult to identify these patterns but the standard is very vague under what conditions we should allow recognition of this pattern. Our interpretation is also discussed more in section 3.2.

These finder pattern has a very high penalty score in order to avoid detection of "false" finder patterns which is the trigger used by QR scanners to detect orientation and position of the barcode. Hence it is considered very bad if a mask creates one or more false finder patterns.

SUMMARY Score = 760 **FALSE 11311 patterns:** Vertical pattern at (5,5) Acc score=40 (No horizontal pattern found) (Real finder pattern detected score=720)	**SUMMARY Score = 720** **FALSE 11311 patterns:** (No vertical pattern found) (No horizontal pattern found) (Real finder pattern detected score=720)

We can see that only the application of mask 3 yields one false vertical finder pattern (see yellow highlight in Figure 1). When applying mask 7 no such false pattern is created. Hence, we know that mask 3 has 40 points higher score in this pattern finding.

The proper finding patterns (prevalent in all matrices) gives a default base score of 720 for both matrices.

2.6 Evaluating the total score

The above sections now allows us to summarize the total score for these two masks as follows

Mask index = 3 Lines: 187 Blocks: 105 11311: 720+40=760 P roportion: 0 ========== **TOTAL score: 1052**	Mask index = 7 Lines: 176 Blocks: 126 11311: 720 Proportion: 0 ========== **TOTAL score: 1022**

Hence we can see that using mask 7 gives an overall lower score solely depending on the fact that we have one "false finder pattern" appearing when applying mask 3.

In Annex G the chosen mask is 3 even though we claim that using mask 7 gives an overall lower score as we have shown above.

3 Discussion

Since the standard is very vague when it comes to detailing the exact intended penalty score evaluation there are some (obvious) degrees of freedom which might affect the score calculation (especially when it comes to the 11311 pattern and the ”sensitivity” for detecting such a pattern). However, even given the obvious possible interpretations (as detailed below) we still claim that mask 3 will never yield the lowest possible score.

The degrees of freedom that are up to the specific implementation to chose from are discussed in following paragraphs.

3.1 Block detection

It is not specified if the finding algorithm should prioritize finding wide over tall blocks when choice exists for a given pattern. This can give marginally different scores

Block example 1: The following example shows evaluation of ”Black” squares with with the two possible strategies (wide or tall first) and as can be seen the resulting score is marginally different.

Wide priority search	Tall priority search
---XXXXX--- ---XXXX---- ---XXXX---- ---XX------ ---XX------ ---XX------ ---XX------ Score = (3-1)*(3-1)*3 + (4-1)*(2-1)*3 = 21	---XXXXX--- ---XXXX---- ---XXXX---- ---XX------ ---XX------ ---XX------ ---XX------ Score = (7-1)*(2-1)*3 + (3-1)*(2-1)*3 = 24

We have (arbitrary) chosen wide over tall as detection strategy in our implementation when there is a choice from the first row in the detected area as in the example above. However, as is shown in the next table if we restrict ourself to a single pass algorihm (as we have done) we might still miss wide patterns

***Block example 2*:** The following example shows the limitation of a single pass algorithm when there is a one column wider block below the start of identified block

Single pass (greedy) algorithm	Multi pass algorithm
---XX---- ---XX--- ---XXX-- ---XXX-- ---XXX-- ---XXX-- ---XXX--- Score = (7-1)*(2-1)*3 = 18	---XX---- ---XX--- ---XXX-- ---XXX-- ---XXX-- ---XXX-- ---XXX--- Score = (2-1)*(2-1)*3 + (5-1)*(3-1)*3 = 27

The standard is not clear if a more complicated multi pass algorithm should be implemented or if it is adequate to stay with a simpler greedy single pass algorithm. The algorithm used in this note is a simpler one pass greedy algorithm. Note that it is only in the case where the wider half is wider by on unit the single pass will yield lower score, if it is two or more units wider it will be found when the next scan line is searched.

As a final note we state (without proof) that the upper limit for the difference, *d*, in the penalty score calculation between a multi pass and single pass algorithm is at most

$$d \leqslant \left|\frac{n}{3}\right| \cdot 3 \cdot (n-4)$$

where *n* is the matrix size (number of rows/columns) and the brackets indicate the integer part after division.

3.2 11311 Pattern detection

Surprisingly this detection is also open to some interpretation. The choice here is down to whether one should require quiet zone on each side of the pattern or if we will allow detection of partial patterns. This is unfortunate not clarified in the standard. The following example illustrates the ambiguity.

Not requiring Quiet zone on the ends	Requiring quiet zones on the ends
--X**X-XXX-X**--**X-XXX-X**--	--XX-XXX-X-**-X-XXX-X**--

In the left example we allow finding ”sub-patterns” without quiet zones on the end and for the above left example we make two detections of the 11311 pattern. However, if we require quiet zones on the ends we will only detect one 11311 pattern as shown in the right highlighting. Our interpretation is that we do require quiet zones on each end of the pattern since this is similar to the real finder patterns.

One further unclearity remains (once we have decided to require quiet zones on the end of the pattern) is if we require quiet zones on the border edges of the matrix? (which we believe to be the proper interpretation). Should we then include the quiet zone surrounding the matrix that is strictly speaking not a part of the matrix layout but of the layout on the entire matrix when printed?

Our interpretation is that we should include the quiet zone surrounding the matrix so that the normal finder patterns are also found by this search. This will of course give an offset of 720 penalty score points for the finding patterns that will always be detected in every matrix.

If, however, one makes the interpretation that we require quiet zone on the end of the 11311 pattern when we search inside the matrix but don't include the implicit quiet zone around the matrix one arrives at the following evaluation for the two masks:

```
Summary score: 40

Mask 3

Vertical Pattern at (5,5) (Acc score=40)


 01234567890123456789
0XXXXXXX-XX-XX-XXXXXXX
1X-----X-X-X---X-----X
2X-XXX-X--XX-X-X-XXX-X
3X-XXX-X-XX----X-XXX-X
4X-XXX-X--XX---X-XXX-X
5X----X--XX---X-----X
6XXXXXXX-X-X-X-XXXXXXX
7--------XX-----------
8X-XX-XXX--X---X--X-XX
9---X-X-XX-X-X--X-XX--
0X--X-XXXX---XXXXX--X-
1XX-X---X--X-XX---X-X-
2---XXXXXX--X-X--X----
3------X--XXX--X-X----X
4XXXXXXX-X----XX-X-XX-
5X-----X-X-XXXXX---X-X
6X-XXX-X--X-X--X-----X
7X-XXX-X-X-X--X--X-XX-
8X-XXX-X-X-XX-X--X-X--
9X-----X--X-XX-X-XX-XX
0XXXXXXX-X--XX--X---X-
```

```
Summary score: 0

Mask 7

(No pattern found)


 01234567890123456789
0XXXXXXX---XXX-XXXXXXX
1X-----X--X----X-----X
2X-XXX-X--XXX--X-XXX-X
3X-XXX-X--X-XX-X-XXX-X
4X-XXX-X--XXXX-X-XXX-X
5X-----X-X-----X-----X
6XXXXXXX-X-X-X-XXXXXXX
7----------X----------
8X--X-XX-X-XXXX-X-----
9XX-X----X-XX-X-X---X-
0-X-X--X-X--X--XXXXX--
1XXX-X--XXX--XXXXXX-XX
2--X--XXX-XXX-XXX----X
3--------X----XX-X----
4XXXXXXX----XX-X-XX---
5X-----X-X-X---X--X-XX
6X-XXX-X--X--XXX--XXXX
7X-XXX-X-XX---XXX--XXX
8X-XXX-X--X-X-XXX--X-X
9X-----X---XXX--X-X-X-
0XXXXXXX-X----X-X-XX--
```

If we instead only search for the 11311 pattern without requiring the quiet zones at each end we find the following alternative penalty evaluation:

```
Summary score: 800

(Real finding pattern detected grayed out)

Mask 3

  Vertical Pattern at (0,2) (Acc score=40)
  Vertical Pattern at (14,2) (Acc score=80)
  Vertical Pattern at (0,3) (Acc score=120)
  Vertical Pattern at (14,3) (Acc score=160)
  Vertical Pattern at (0,4) (Acc score=200)
  Vertical Pattern at (14,4) (Acc score=240)
  Vertical Pattern at (6,5) (Acc score=280)
  Vertical Pattern at (2,10) (Acc score=320)
  Vertical Pattern at (0,16) (Acc score=360)
  Vertical Pattern at (0,17) (Acc score=400)
  Vertical Pattern at (0,18) (Acc score=440)

  Horizontal Pattern at (2,0) (Acc score=40)
  Horizontal Pattern at (2,14) (Acc score=80)
  Horizontal Pattern at (3,0) (Acc score=120)
  Horizontal Pattern at (3,14) (Acc score=160)
  Horizontal Pattern at (4,0) (Acc score=200)
  Horizontal Pattern at (4,14) (Acc score=240)
  Horizontal Pattern at (16,0) (Acc score=280)
  Horizontal Pattern at (17,0) (Acc score=320)
  Horizontal Pattern at (18,0) (Acc score=360)

 01234567890123456789
0XXXXXXX-XX-XX-XXXXXXX
1X-----X-X-X---X-----X
2X-XXX-X--XX-X-X-XXX-X
3X-XXX-X-XX----X-XXX-X
4X-XXX-X--XX---X-XXX-X
5X-----X--XX---X-----X
6XXXXXXX-X-X-X-XXXXXXX
7--------XX-----------
8X-XX-XXX--X---X--X-XX
9---X-X-XX-X-X--X-XX--
0X--X-XXXX---XXXXX--X-
1XX-X---X--X-XX---X-X-
2---XXXXXX--X-X--X----
3--------XXX--X-X----X
4XXXXXXX-X----XX-X-XX-
5X-----X-X-XXXXX---X-X
6X-XXX-X--X-X--X-----X
7X-XXX-X-X-X--X--X-XX-
8X-XXX-X-X-XX-X--X-X--
9X-----X--X-XX-X-XX-XX
0XXXXXXX-X--XX--X---X-
```

```
Summary score: 760

(Real finding pattern detected grayed out)

Mask 7

  Vertical Pattern at (0,2) (Acc score=40)
  Vertical Pattern at (14,2) (Acc score=80)
  Vertical Pattern at (0,3) (Acc score=120)
  Vertical Pattern at (14,3) (Acc score=160)
  Vertical Pattern at (0,4) (Acc score=200)
  Vertical Pattern at (14,4) (Acc score=240)
  Vertical Pattern at (0,16) (Acc score=280)
  Vertical Pattern at (0,17) (Acc score=320)
  Vertical Pattern at (0,18) (Acc score=360)

  Horizontal Pattern at (2,0) (Acc score=40)
  Horizontal Pattern at (2,14) (Acc score=80)
  Horizontal Pattern at (3,0) (Acc score=120)
  Horizontal Pattern at (3,14) (Acc score=160)
  Horizontal Pattern at (4,0) (Acc score=200)
  Horizontal Pattern at (4,14) (Acc score=240)
  Horizontal Pattern at (12,7) (Acc score=280)
  Horizontal Pattern at (16,0) (Acc score=320)
  Horizontal Pattern at (17,0) (Acc score=360)
  Horizontal Pattern at (18,0) (Acc score=400)

 01234567890123456789
0XXXXXXX---XXX-XXXXXXX
1X-----X--X----X-----X
2X-XXX-X--XXX--X-XXX-X
3X-XXX-X--X-XX-X-XXX-X
4X-XXX-X--XXXX-X-XXX-X
5X-----X-X-----X-----X
6XXXXXXX-X-X-X-XXXXXXX
7----------X----------
8X--X-XX-X-XXXX-X-----
9XX-X----X-XX-X-X---X-
0-X-X--X-X--X--XXXXX--
1XXX-X--XXX--XXXXXX-XX
2--X--XXX-XXX-XXX----X
3--------X----XX-X----
4XXXXXXX----XX-X-XX---
5X-----X-X-X---X--X-XX
6X-XXX-X--X--XXX--XXXX
7X-XXX-X-XX---XXX--XXX
8X-XXX-X--X-X-XXX--X-X
9X-----X---XXX--X-X-X-
0XXXXXXX-X----X-X-XX--
```

So, even with this interpretation index 7 mask gives an overall lower score of the 11311 pattern search.

There is one final possible variant of the 11311 pattern search we would like to mention. One plausible interpretation is that we should also look for 11311 patterns starting with a white module, i.e. looking for inverted finder patterns. However, based on the wordings in the standard where it for lines and blocks specifically mentions *color***s** (meaning looking both for white and black modules) this wording is not used for the 11311 pattern search description. Hence we have made the interpretation to only look for proper finder patterns and not for inverted patterns (which also makes sense based on the workings of scanners).

4 Conclusion

In this note we have shown that there is a minor error in the standard for the QR barcode in Annex G (encoding example) where the Annex have selected mask 3 as the final XOR mask. The mask with the lowest penalty score that should have been chosen is mask 7.

It is possible that the selection made in Annex G in the standard is a somewhat arbitrary choice rather then selected because the chosen mask gives the lowest possible penalty points. However, that would then be a deviation from the standard since the mask selection is normative. Since it is not specified in Annex G how (or why) mask 3 was chosen we cannot further comment on this. However, this should be considered a textual weakness in the standard that should be expanded on in future revisions.

However, this is a not a critical mistake since the consequence is small since the selection of the mask is non-critical. One could even argue that it is possible to deviate from the standard and just randomly select a mask without really affecting the scanner reading accuracy in practice.

Our interpretation of the standard is such that the penalty calculation is normative and should be performed according to the schema detailed in this note and hence mask 7 should be chosen to strictly adhere to the standard.

A consequence of the low level of detailing in the description of the penalty score is that several popular QR barcode creation SW have made different interpretation on how to make the mask selection. This then gives different visual appearance of barcodes for the same data even though the same encodation schemas are used.

For the next revision of the standard a new Annex similar to this note should be added detailing the exact penalty score calculation to reduce the number of possible interpretations of the standard.

Appendix A. Definition of mask pattern

In order to avoid any misunderstanding we here state exactly how the index = 3 and index = 7 masks are calculated.

Index=3 mask (011)	**Index=7 mask (111)**
$(i+j) \bmod 3 = 0$	$((i \cdot j) \bmod 3 + (i+j) \bmod 2) \bmod 2 = 0$ ***Note:*** *In figure 17 in the standard this condition is wrongly stated as the same as for mask 110*

Optical verification yields that Annex G in the standard correctly identifies index 3 with the above condition since applying this condition yields the exact same result as shown in Annex G in the standard.

Appendix B. Error in figure 17 in the ISO/IEC standard

We would also like to point out an error in Figure 17 (page 51) in the QR standard [1]. In the graphical illustration of the different masks the bottom row shows two masks with index 6 where the last mask should really be index 7, i.e. the figure incorrectly shows mask 7 (111) being evaluated as

$$((i \cdot j) \bmod 2 + (i \cdot j) \bmod 3) \bmod 2 = 0$$

which is wrong since this is the condition for mask index 6 (110).

Appendix C. Annotation to Annex C – precomputed bit sequence for format information using BCH (15,5) error correction

In the standard, Annex D lists a table of precomputed bit sequences for the version information that should be put in the matrix. This is based on calculating the corresponding BCH (18,6) code given the raw bit sequencing for the version information and then combining the two bit sequences into the final bit stream to be placed in the matrix.

However, there is no such corresponding table for the format information that should be treated in a very similar way. We believe this to be an inconsistency in the standard.

The format information consists of the combined bit sequence for the error correction level and the optical mask index. The final format information is then augmented with a BCH (15,5) code to yield the error redundancy bits.

For consistency we would like to suggest adding a variant of the following table to Annex C in the next revision of the standard for consistency with Annex D and to reduce risks for implementation errors.

Format bits (Error level + Mask index)	Format bits + BCH (15,5) error correction code	Final bit sequence for format information after applying XOR mask '101010000010010'
00000	000000000000000	101010000010010 (5412)
00001	000010100110111	101000100100101 (5125)
00010	000101001101110	101111001111100 (5E7C)
00011	000111101011001	101101101001011 (5B4B)
00100	001000111101011	100010111111001 (45F9)
00101	001010011011100	100000011001110 (40CE)
00110	001101110000101	100111110010111 (4F97)
00111	001111010110010	100101010100000 (4AA0)
01000	010001111010110	111011111000100 (77C4)
01001	010011011100001	111001011110011 (72F3)
01010	010100110111000	111110110101010 (7DAA)
01011	010110010001111	111100010011101 (789D)
01100	011001000111101	110011000101111 (662F)
01101	011011100001010	110001100011000 (6318)
01110	011100001010011	110110001000001 (6C41)
01111	011110101100100	110100101110110 (6976)
10000	100001010011011	001011010001001 (1689)
10001	100011110101100	001001110111110 (13BE)
10010	100100011110101	001110011100111 (1CE7)
10011	100110111000010	001100111010000 (19D0)
10100	101001101110000	000011101100010 (0762)
10101	101011001000111	000001001010101 (0255)
10110	101100100011110	000110100001100 (0D0C)
10111	101110000101001	000100000111011 (083B)
11000	110000101001101	011010101011111 (355F)
11001	110010001111010	011000001101000 (3068)
11010	110101100100011	011111100110001 (3F31)
11011	110111000010100	011101000000110 (3A06)
11100	111000010100110	010010010110100 (24B4)
11101	111010110010001	010000110000011 (2183)
11110	111101011001000	010111011011010 (2EDA)
11111	111111111111111	010101111101101 (2BED)

References

[1] International standard ISO/IEC 18004:2000(E), (First edition 2000-06-15), *Information technology — Automatic identification and data capture techniques — Bar code symbology — QR Code*