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QR Code Grading Parameters

Summary

QR Code symbols are graded by checking each square cell and comparing its color to the color it is supposed to be. The process begins by finding the QR Code symbol within an image, which is based on the large finder patterns which are found in three of the corners of a QR Code symbol. Once those patterns are found, the clock tracks and alignment patterns are used to establish a grid of symbol. The intersections of the grid fall at or near the center of each module. The color o the module is measured at the intersection of the grid lines.

When the color of a module is measured, the intersection of the grid lines is actually the center of a circular area called the “Aperture”, which is a circle of a certain defined diameter. The color of the image will often vary within that circular area. The average color within that circular area is the color used when evaluating the module for its color.

The color of a module is determined to be either dark or light based on whether or not the average color for the module is above (lighter than) or below (darker than) a middle color level that is called the Global Threshold. The Global Threshold is actually a gray color that is midway between the darkest and lightest color levels found within the symbol. This means that if a symbol is printed on a dark background, the Gobal Threshold will adapt to the background because it will be midway between the color of the background and the dark modules.

Once a module is determined to be dark or light, that is not the only check on its color. The actual color level is compared to the Global Threshold to see how close the color is to the Global Threshold. A light module should not be close in color to the Global Threshold. In fact it should be close in color to the brightest color in the symbol. A dark module should be close in color to the darkest color in the symbol. It is uncertain whether a module is intended to be dark or light, when the color of the module is in fact close to the Global Threshold. Therefore, modules are graded based on their color along a scale of 0% at the Global Threshold to 100% at color that it is supposed to be. When the color of a module is half way between these two levels, the color grade (also called Modulation) for that module is 50% and that is the break point between A and B grades for Modulation. As the color gets closer to the Global Threshold, the grade slips to a C, then D and finally F.

Grading of a QR Code symbol depends on these color grade assignments of the modules within the symbol. Exactly how each module’s color figures into the grading is described in the remaining sections below. Some modules are part of finder patterns. Others are part of clock tracks. Still others are part of Version Information Blocks, Format Information Blocks, Alignment Patters, and just regular data modules which encode a one or a zero. The grading rules for each modules is different and is derived from how an error to one or more modules having each purpose effects the readability of the QR Code Symbol. The details below give these exact rules and depict where each section of modules occur within QR Code Symbols.

The Fixed Pattern of QR Code Symbols consist of :

- ✓ 3 large finder patterns
- ✓ Two clock tracks: horizontal and vertical
- ✓ An array of alignment patterns.
- ✓ Version information Block
- ✓ Format Information Block

The following sections depict each of these elements of the fixed pattern and defines the grade assignment rules for each one.

Part 1: Finder Patterns at Upper Left, Upper Right and Lower Left of the Sybmol

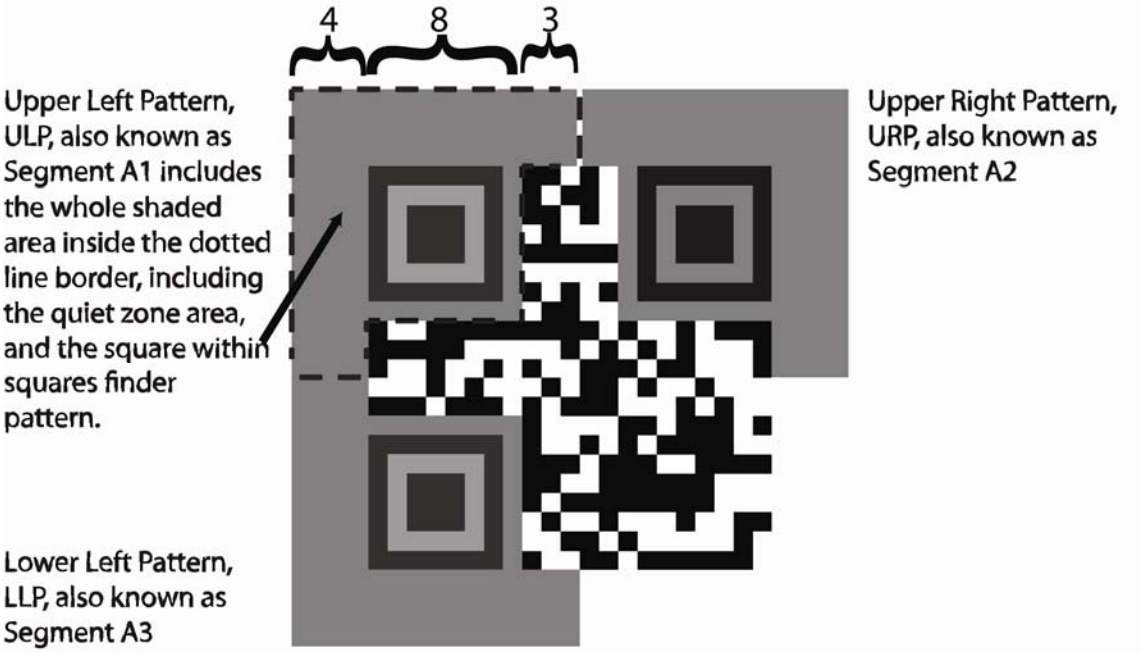

Figure 1
The three main finder patterns of a QR Code symbol is shown for a Version 1 symbol which is the smallest Qr Code. The finder pattern grade is computed by counting how many modules within each pattern are incorrect (see Table 1). Note that for each pattern, the area includes: - all the modules within the 7x7 squares within squares pattern
- the two separators which are one module wide and adjacent to these patterns on the inside of the symbol
- the quiet zone area outside the symbol, which extends for 3 modules beyond each separator towards the middle of the symbol. (On this smallet version symbol the quiet zones associated with teh Upper Left and Upper Right patterns adjoin and in fact share one column of modules where they overlap, and this also occurs on the left side of the symbol where the Upper Right pattern and the Lower Left pattern adjoin.

Table 1 Grade assignments based on Segment A Patterns

Number of Incorrect Modules	Grade
0	A
1	B
2	C
3	D
4 or more	F

Frequently asked questions about QR Code ULP (A1), URP (A2), and LLP(A3) Grading:

1. What is meant by “an incorrect module” in the finder pattern?
   An incorrect module is one that is supposed to be light and is dark instead, or the opposite (a module that is supposed to be dark, but is light). In fact, the grading is a little more complicated however, because a module is also measured on the degree to which it has the correct color and graded accordingly.

2. How does the color of a module affect the grade, if the module is still decoded as the correct color?
   The color of a module is evaluated to see how close it is the global threshold. If it is a light module, then it is evaluated along the range of color starting from the global threshold (0% good) up to Rmax (100%) which is the brightest light element in the symbol. The value of a modules reflectance along this range is known as its modulation. Each module is evaluated for its modulation and given a modulation letter grade (A through F) and that is the highest grade that can be given to the pattern. Therefore, the “number of incorrect modules” in Table 1 above is really “number of modules with modulation below a grade of A, B, C, D or F modulation.

3. How will an incorrect module in the quiet zone in the area where the quiet zones overlap affect the grade?
   Any module that occurs in more than one pattern which independently be counted in each pattern.

4. Is the grade affected more if there are incorrect modules in more than one of the three patterns?
   The overall grade will be driven by the pattern with the lowest grade, so it does not matter how many incorrect modules occur in other patterns. This means that if one pattern has a C grade, the other patterns can be A, B, or C without further affecting the overall grade.

5. How do small printing imperfections, such as small spots and voids affect the grade?
   The color of a module is evaluated within a circular area that is centered at (what is determined by the reference decode algorithm to be) the module center, and this circle is the size of the “aperture”. Small spots and voids will have a correspondingly small affect on the average color over this whole aperture area. Moreover, spots and voids which are between aperture circles (because they are located between, but not near, module centers will not affect this at all.

Part 2: Horizontal Clock Track and Vertical Clock Track

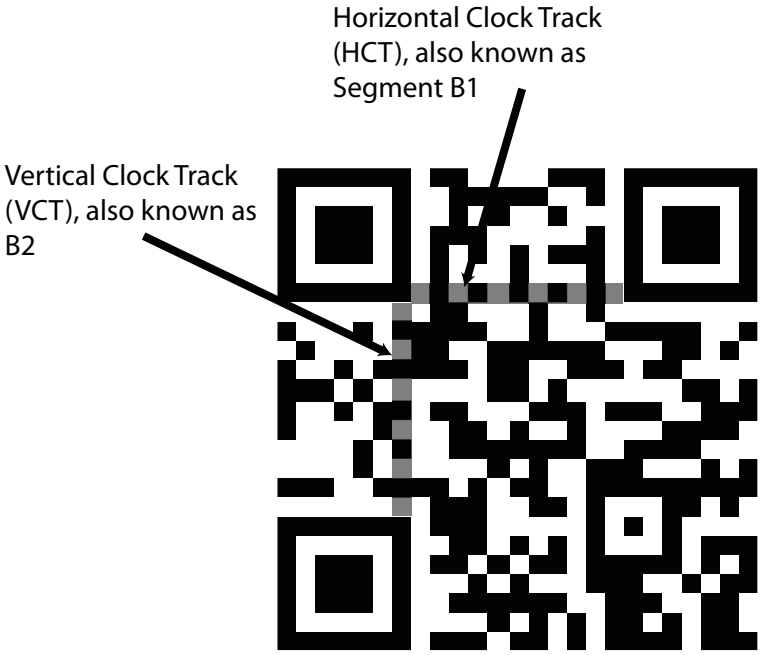

Figure 2
clock Tracks in a QR Symbol eminate from the corner of the upper left pattern and create an alternating light/dark pattern until reaching the other pattern.

Table 2 Grade assignments based on Clock Tracks

Number of Incorrect Modules	Grade
0	A
≤ 7%	B
≤11%	C
≤14%	D
> 14%	F

Part 3: Alignment Patterns

On larger QR Code Symbols there are one or more alignment patterns. The alignment patterns are smaller “square within square” patterns as depicted in Figure 3.

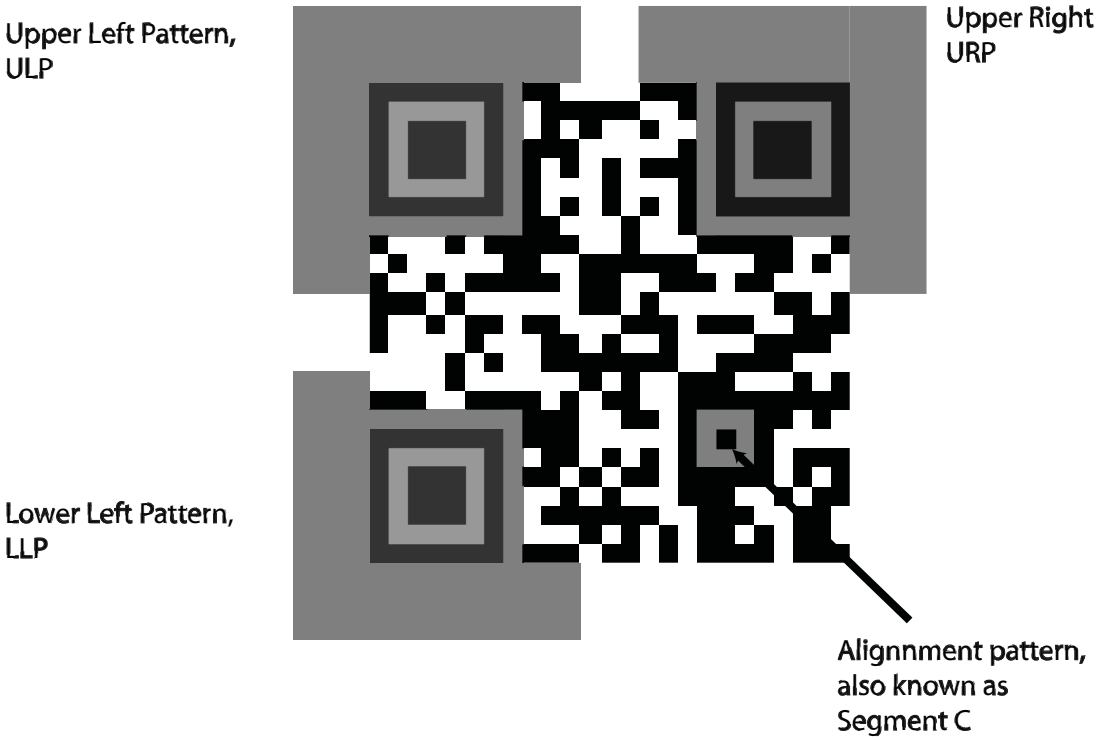

Figure 3
Finder patterns in a Version 2 QR Code symbol. In this case the finder patterns are seperated and the quiet zones are only checked in the regions near the finder patterns. Also, in this and all larger symbols there are allignment patterns.

Figure 4
A larger QR Code symbol which has many Alignment Patterns. A QR Code symbol must have at least 45 modules across for it to have more than one alignment pattern.

Grading of QR Code Alignment Patterns

Each alignment pattern is examined to see if there are ANY incorrect modules within it. Then the grade is assigned based on the percentage of alignment patterns with any such errors. Note that when there is only one alilgnment pattern, any damage to that pattern will result in an F grade.

Table 3 Grade assignments based on Alignment Patterns

Percentage of alignment patterns with any module errors	Grade
0	A
≤ 10	B
≤ 20	C
≤ 30	D
> 30	F

Part 4: Version Information Block

Version Information Blocks occur in larger QR Code symbols only (those with 45 x 45 modules or larger). These blocks are repeated in two places in the symbol to provide redundancy protection against damage to either one.

Table 4 Grade assignments based on Version Information Blocks

Number of Incorrect Modules	Grade
0	A
1	B
2	C
3	D
> 3	F

Since the Version Information Block is repeated with the Symbol, even if one is damaged, the other can be used to decode the symbol. Therefore, the grade for the VersionInformation Block is actually the average of the Grades of the two. For example, if one of the version information blocks has two modules that are incorrect and therefore is graded as a C, and the other one is not damaged at all and gets an A grade, then the grade for the Version Information Blocks will be B.

Part 5: Format Information Block

The Format Information Block is a set of 15 modules that indicate the error correction level and the “mask pattern” that was used when the symbol was encoded. This information is critical to the decoding process in order to perform error correction and to “undo” the mask for the purpose of decoding.

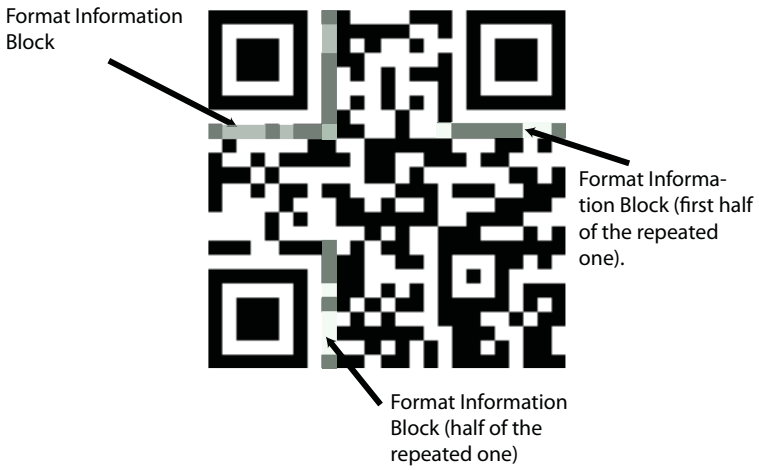

Figure 4
Format Information Blocks. The data inthe format information block is repeated.

What is “masking” and what is a “mask pattern”?

It is very common for some bar code symbols to contain data that repeats, especially with values of zero0. In such a case in a QR Code symbol, the data modules may be mostly all black or all white. In order for the symbol to contain a pattern that appears to be “random” and evenly split between white and black modules, the symbol data is modified in a predictable way by “masking”., This means that instead of a dark module always representing a 1 always represebut changing the state of white and black modules which represent a 1 or 0 in a random way. However, because some data patterns may accidently mimic the sequence of 1 and 0 mask bits, the process of masking may actually create a symbol that is “worse” than the unmasked pattern. To combat this, there are more than one mask sequences and the best one for a particular set of data to be encocded is chosen when the symbol is encoded. Because there is no other way to know which mask was used when encoding, the mask is given directly in the format information block.

Table 5 Grade assignments based on Format Information Blocks

Number of Incorrect Modules	Grade
0	A
1	B
2	C
3	D
> 3	F

Since the Format Information Block is repeated with the Symbol, even if one is damaged, the other can be used to decode the symbol. Therefore, the grade for the Format Information Block is actually the average of the Grades of the two. For example, if one is damaged completely and gets an F grade, and the other one is not damaged at all and gets an A grade, then the grade for Format Information Blocks will be C.

Additional Grading Parameters for QR Code Symbols

In addition to the fixed patterns in the QR Code symbol, these other parameters are graded. These are the parameters that are graded for any 2D symbology, not just QR Codes.

Decode

Any QR Code symbol has to be decodable by following the process given in the QR Code specification for creating the grid of modules, which depends upon the finder patterns, clock tracks, etc. – basically all of the elements of the fixed pattern. Sometimes, these are so damaged that the symbol cannot be decoded at all, and is therefore given an F grade. So, if the symbol does succeed in decoding, then the Decode parameter is given an A grade which means that the actual grade of the symbol will depend upon the grade of the fixed pattern, or the other parameters listed below.

Unused Error Correction (UEC)

QR Code symbols, like most 2D symbologies, contain error correction which enable the decoder to succeed in recovering all of the bits of data in the symbol even if some of the data modules are the incorrect color (either by printing or by dirt of other damage). The error correction capability is limited to a certain number of modules however, and the percentage of error correction capability that is used up or left remaining determines the grade for Unused Error Correction (UEC).

Table 6 Grade assignments based on UEC

Amount of unused error correction	Grade
≥ 62%	A
≥ 50%	B
≥ 37%	C
≥ 25%	D
<25%	F

Axial Non-Uniformity (ANU)

QR Code Symbols are normally square and each cell is a square. Any stretch in the symbol that affects the aspect ratio of the modules will be measured as Axial Non-Uniformity (ANU). The value of ANU is computed by dividing the difference in the lengths of the two axis by the average length of the two axis.

Table 7 Grade assignments based on ANU

Axial Non-Uniformity	Grade
≤ 6%	A
≤ 8%	B
≤ 10%	C
≤ 12%	D
> 12%	F

Grid Non-Uniformity (GNU)

The decoding process results in the grid of intersecting lines which are supposed to be located at the centers of modules. Ideally, the grid would be equally spaced in vertical and horizontal directions. However, the grid will adapt to the positions of the clock track modules and the alignment patterns, so in fact it will not be equivalent to the ideal grid which would be equally spaced between the centers of the large finder patterns.

Grid Non-Uniformity measures the largest difference between the grid intersections of the actual (adaptive decoding grid) and the ideal grid (equally spaced between finder patterns), as a percentage of the X dimension.

Table 8 Grade assignments based on GNU

Amount of Grid Non-Uniformity	Grade
≤ 38%	A
≤ 50%	B
≤ 63%	C
≤ 75%	D
> 75%	F

Modulation (MOD and RM)

Modulation is a measurement of data bit modules which is based on their color, compared to the Global Threshold and the color level that these modules are supposed to be. The closer to the Global Threshold, and therefore more uncertain they are, the lower the grade for that module. The percentage of modules with each color level determines the grade assignment.

Since there is error correction capability, a relatively small number of modules which are uncertain in color does not cause a symbol to be unreadable, or even difficult to read. As more modules become uncertain however, the symbol does become more difficult to read or at least the symbol will be less resilient against any dirt of damage that may occur to the symbol during its “lifetime”.

To produce the grade of Modulation, the color of each module is graded and those with grades lower than A are counted as errors for the purpose of computing a grade based on the formula for unused error correction. Then, the same is done for all modules limited by (lower than) B, C, and D. The grade is calculated as the “best of the worst”, meaning that for each limiting grade, the lower of the limiting grade and the UEC result is selected and the final grade for MOD or RM is the highest of these selections.

The difference between MOD and RM is that for MOD, modules which are in fact the wrong color are not automatically counted as errors, but instead their color on either side of the global threshold (that is, without regard for the actual color that the module should be) is used to assign its grade. For RM, modules which are incorrect are always counted as errors. Because of this, MOD is useful only for evaluating a printing process without regard to the module values, but should not be used to judge how readable a symbol is. On the other hand, RM related more closely to the readability of a symbol because modules which are indeed the wrong color are counted as errors.

Since, the overall grade of a symbol will be the lower of all the parameters, the lower of MOD and RM will determine the final grade. Moreover, since RM will always be equal to or less than MOD, RM will always determine the final grade rather than MOD. In this sense MOD is unnecessary to determine the final grade of a symbol but may be useful to evaluating a printing process in some cases.

Additional Frequently Asked Questions about QR Code Symbols

Why are the grades of the two format information blocks (and the version information blocks) averaged?

The decoding process can rely upon either one of the two copies of these blocks. Normally the decoding algorithm will evaluate both of these blocks and determine which one is correct (based on error correction). When one is hard to read, it will slow down, but not prevent the decoding from succeeding. Therefore, the grade is lowered.

What is the difference between symbols which get higher or lower grades?

Symbols with higher grades are easier to read and will therefore be read faster and with less effort by the user. A symbol which has print quality problems, but is still readable, may force the user to more carefully focus the reader in front of the symbol and wait for the decode to succeed.

What is the required grade for a QR Code to be considered "Good"?

A well printed code should get an A or B grade, but any code with a C or higher grade is considered readable (although the C may be slightly harder to read than the B or A codes).

What aperture size should be used to grade a QR Code Symbol?

The aperture size should be specified by an industry standard or guideline that you follow. If you have none, you should consider what is the best way to determine the readability of the symbol, such as by following Webscan's recommendations below.

Does Webscan recommend a certain aperture size for grading QR Code Symbols which are intended to be read by cell phones?

Yes. For QR Codes which are intended to be read by cell phones, Webscan recommends an aperture size of 10 mil.

Does Webscan recommend a module size (X dimension) for QR Code Symbols which are intended to be read by cell phones?

Yes, For QR Codes which are intended to be read by cell phones, Webscan recommends an X dimension of 30 mil or larger. However, it is also important to keep the overall size of the QR Code Symbol small enough to be scanned easily. Therefore, we further recommend that the overall symbol not be larger than one inch wide. This means that the QR Code symbol should be made in a format of 29 x 29 modules are less.

How can an internet address (URL) be fit into a QR Code symbol of 29 x 29 modules or less?

Short URL's should be used, and redirected to any page required, rather than directly encoding a deep URL into the QR Code symbol. For instance, the URL: www.webscaninc.com/qr101 can be encoded in a 25 x 25 module QR Code which is shown below.

This URL can be redirected to any page necessary (for easy organization of your website) but it is more efficient to encode only this "key" into the QR Code symbol, than to encode a deep URL into the QR Code Symbol.

Where do the rules for printing and grading QR Codes come from?

The rules for QR Ccde, including printing and grading are contained in a document published by ISO. The document is called ISO/IEC 18004. The latest version of this document may be purchased from ISO at www.iso.org.

Where can I find more information about QR Codes?

Many companies offer information about QR Codes, but this information tends to center around the use of QR Codes for successful marketing, not about QR Code print quality and grading. However, there are some guidelines published by companies which sell QR Code marketing services which offer useful guidance, although we do not wish to list any company names. Feel free to call or email us at Webscan with any questions or comments. We can be reached at 1-877-WEBSCAN or by email at support@webscaninc.com.