Teaching guide: Run-length encoding

This teaching guide is designed to help you teach Run-length encoding from the GCSE Computer Science specification (8520). It is not prescriptive; it simply gives you some teaching ideas that you can adapt to the needs of your students.

Run-length encoding (RLE) is a form of lossless compression

RLE is a simple method of compressing data by specifying the **number of times** a character or pixel colour repeats followed by the **value** of the character or pixel. The aim is to reduce the number of bits used to represent a set of data. Reducing the number of bits used means that it will take up less storage space and be quicker to transfer.

There are many different compression methods. Compression methods can be categorised as being lossless or lossy. With lossless compression none of the original data is lost when it is compressed, whereas when a lossy compression method is used some of the original data is lost during the compression process which cannot be retrieved when the data is decompressed.

There are times when lossy compression is the best choice – either when a significantly smaller file size is desired or if the data loss is not noticeable eg there are many sounds that people cannot hear and if compression results in the loss of some of these sounds then the data loss is not important.

Lossy compression can often compress the data further than lossless compression (ie results in fewer bits being used).

For a text file, however, it is critical that no data is lost and therefore a lossless compression method must be used.

RLE for text data

The process involves going through the text and counting the number of consecutive occurrences of each character (called "a run"). The number of occurrences of the character and the character code are then stored in pairs. The first part of the pair is the count and the second part is the character.

Example: `aaaabbbbbbcddddd`

There are 16 characters in the example so 16 bytes (assuming ASCII is being used) are needed to store these characters in an uncompressed format:

Example as ASCII: `97 97 97 97 98 98 98 98 98 98 99 100 100 100 100 100`

However, RLE can be used to store that same data using fewer bytes. There are four consecutive occurrences of the character 'a' followed by six consecutive occurrences of 'b', one 'c' and finally five consecutive occurrences of 'd'. This could be written as the following sequence of occurrence-character pairs:

Run-length encoding for the above Example: `(4,a) (6,b) (1,c) (5,d)`

If this text is then compressed using RLE we would end up with: `04 97 06 98 01 99 05 100`

As we can see, this compressed version only requires 8 bytes - a reduction from the original 16 bytes (assuming each number is also represented using one byte).

Text that has characters with a high frequency of repetition can be compressed efficiently. Text with few repetitions, ie more random text, will not compress well and can even result in negative compression – when the compressed version uses more storage space than the uncompressed version.

A possible solution to this is to use a special byte value that 'flags' when a run is going to occur. This does mean though that any run of bytes automatically has an additional byte added to it. When there is no flag, the next byte(s) are taken as their face value and with a run of 1.

Example

Uncompressed

`aaaaaaaaaabbbbbbeceeceeceecdddddddddddddddecb` (46 bytes)

No Flag RLE

`10 97 06 98 01 101 01 99 01 101 01 99 01 101 01 99 01 101 01 99 01 101 01 99 01 101 01 99 15 100 01 101 01 99 01 98` (36 bytes)

Flag (value 255) RLE

`255 10 97 255 06 98 101 99 101 99 101 99 101 99 101 99 255 15 100 101 99 98` (24 bytes)

RLE for bitmapped image data

RLE for bitmapped image compression works in a similar way to text compression. The effectiveness depends on the image being compressed; images with long runs of pixels of the same colour will provide a higher compression ratio than images that have frequently changing colours.

There are several ways of using RLE on bitmapped images: bit level RLE, byte level RLE and pixel level RLE.

Bit Level RLE (for black and white images)

Bit level RLE is effective when one bit is used to represent the colour of each pixel. Here a single byte represents the value of a pixel and the run length. Within the 8 bits, the left-most bit identifies the colour (eg `1` = white and `0` = black) the next 7 bits identify the run length.

The example below shows a section of 32 pixels from a monochrome bitmap:

The uncompressed representation would be `11111100000000001111111111111111`.

When compressed using bit level RLE, the first six pixels are black so the left-most bit in the first byte of the encoding would be a 1 (underlined in the example below) followed by the 7-bit binary number representing 6.

`10000110`

The second ten pixels are white (see the underlined 0 in the example below) and so the next byte in the encoding would be:

`00001010`

The complete encoding including the final 16 black pixels is:

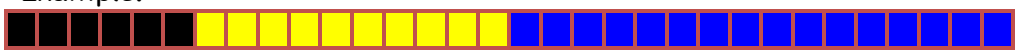
`10000110 00001010 10010000`

The original bitmap used 32 bits whereas the bit level RLE of the bitmap uses only 24 bits. This compression works due to the relatively long sequences of consecutively-coloured pixels.

Byte level RLE - (for 256-colour images)

Each pixel (colour) is represented by a single byte giving 256 possibilities. The codes for the colours would be detailed within a colour palette table which would be stored in the image file. The colour palette is arbitrary and determined by factors such as hardware, image composition or file type. The image data is then represented by pairs of bytes representing the run length and then the run colour.

Example:



6 black, 10 yellow, 16 blue

If the colour table for the example above specified black as 16, yellow as 126 and blue as 20 then the corresponding bytes would be:

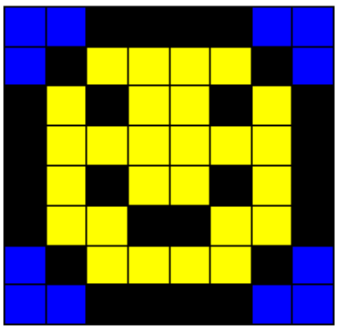
00000110 00010000 00001010 01111110 00010000 00010100

As with text compression a flag byte could be used to prevent negative compression.

Pixel level RLE (16.7 million colour images)

Each pixel is represented by multiple bytes, ie four bytes, for an RGB bitmap. Each pair would consist of a run length byte, followed by the three bytes that represent the pixel colour.

The meta-data for a bitmap will include the number of rows and number of columns (e.g. 8x8), so it is safe for the RLE to 'run over' a row, ie reading from the top-left pixel, the image can be encoded as two blue pixels, four black pixels, three blue pixels, etc.



RGB Colour Values			
	R	G	B
	0	0	255
	255	255	255
	255	255	0

This image uses three bytes per pixel and so the total UNCOMPRESSED file size (ignoring meta-data) is 8 x 8 x 3 = 192 bytes.

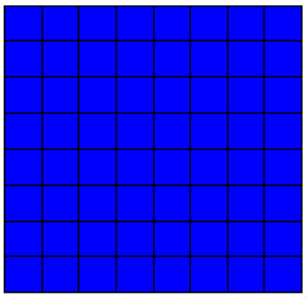
Example RLE for the 8 x 8 face shown above

For presentation purposes, the data is shown as three sets of 4 bytes per row, in the actual file this would simply be a continuous row of data.

Count	R	G	B	Count	R	G	B	Count	R	G	B
2	0	0	255	4	255	255	255	3	0	0	255
1	255	255	255	4	255	255	0	1	255	255	255
1	0	0	255	1	255	255	255	1	255	255	0
1	255	255	255	2	255	255	0	1	255	255	255
1	255	255	0	2	255	255	255	6	255	255	0
2	255	255	255	1	255	255	0	1	255	255	255
2	255	255	0	1	255	255	255	1	255	255	0
2	255	255	255	2	255	255	0	2	255	255	255
2	255	255	0	1	255	255	255	1	0	0	255
1	255	255	255	4	255	255	0	1	255	255	255
3	0	0	255	4	255	255	255	2	0	0	255

Each cell in the table requires one byte hence the total bytes required for the RLE of the bitmap is 132 bytes. This is a file size 68.75% of the size of the original.

Best case scenario

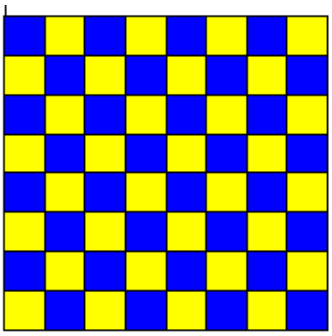


The longer the run lengths the better the compression, therefore if we only had one colour we could specify the entire 64 pixel image with just 4 bytes.

	R	G	B
64	0	0	255

TOTAL BYTES REQUIRED = 4 bytes

Worst case scenario



Conversely, the shorter the run lengths the less compression we achieve. The worst case being that we change the colour every pixel.

Each pixel takes exactly 4 bytes EVERY time, no runs.

TOTAL BYTES REQUIRED = 64 x 4 = 256 bytes

File sizes

The actual file size of compressed data will often be larger than indicated by the examples shown in this document as there will also be metadata stored in the file (along with the character/pixel data).