Compression: Images (JPEG)

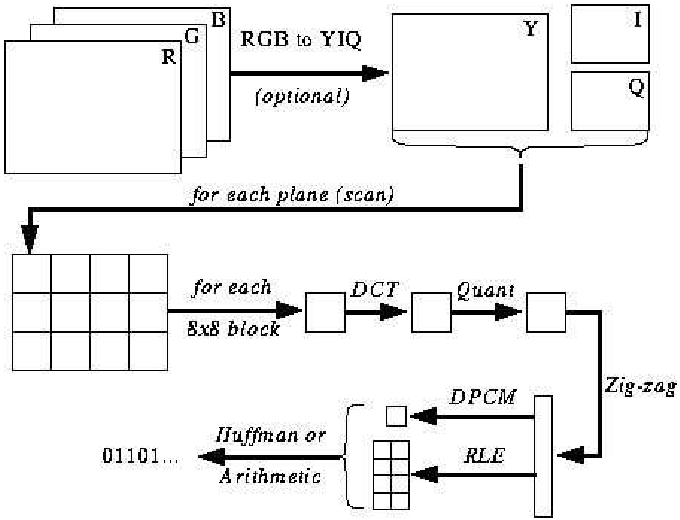
What is JPEG?

- **JPEG: Joint Photographic Expert Group** — an international standard since 1992.
- Works with colour and greyscale images
- Up to **24 bit colour** images (**Unlike GIF**)
- Target **photographic** quality images (**Unlike GIF**)
- Suitable for many applications e.g., satellite, medical, general photography...

Basic JPEG Compression Pipeline

JPEG compression involves the following:

- Encoding



- Decoding – Reverse the order for encoding

Major Coding Algorithms in JPEG

The Major Steps in JPEG Coding involve:

- Colour Space Transform and subsampling (YIQ)
- DCT (Discrete Cosine Transformation)
- Quantization
- Zigzag Scan
- DPCM on DC component
- RLE on AC Components
- Entropy Coding — Huffman or Arithmetic

We have met most of the algorithms already:

- JPEG exploits them in the compression pipeline to achieve maximal overall compression.

Quantization

Why do we need to quantise:

- To throw out bits from DCT.
- *Example*: 101101 = 45 (6 bits).

  Truncate to 4 bits: 1011 = 11.

  Truncate to 3 bits: 101 = 5.

- Quantization error is the main source of **Lossy Compression.**
- **DCT itself is not Lossy**
- How we **throw away bits** in **Quantization Step** is **Lossy**

Quantization Methods

Uniform quantization

- Divide by constant N and round result (N = 4 or 8 in examples on previous page).
- Non powers-of-two gives fine control (e.g., N = 6 loses 2.5 bits)

Quantization Tables

- In JPEG, each F[u,v] is divided by a constant q(u,v).
- Table of q(u,v) is called *quantization table*.
- Eye is most sensitive to low frequencies (upper left corner), less sensitive to high frequencies (lower right corner)
- JPEG Standard defines 2 default quantization tables, one for luminance (below), one for chrominance. *E.g Table below*

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

Quantization Tables (Cont)

- Q: How would changing the numbers affect the picture

  E.g., if we doubled them all?

  Quality factor in most implementations is the **scaling factor** for default quantization tables.

- **Custom quantization tables** can be put in image/scan header.

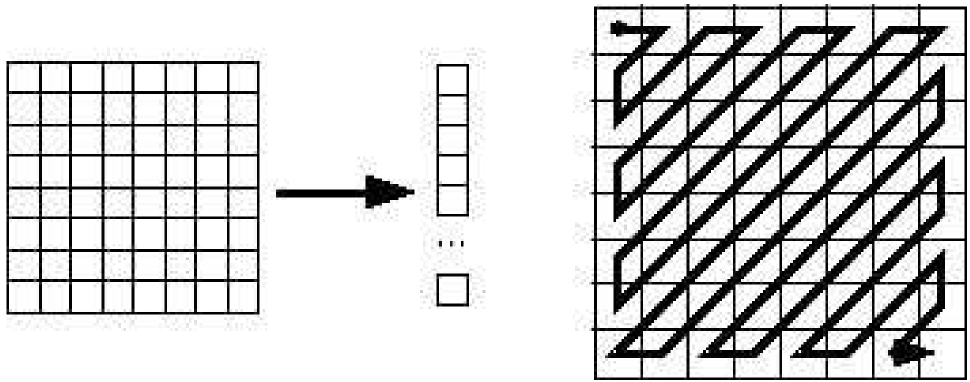
JPEG Quantisation Examples

- JPEG Quantisation Example (Java Applet)
- Another JPEG Quantisation Example (Java Applet)

Zig-zag Scan

What is the purpose of the Zig-zag Scan:

- To group low frequency coefficients in top of vector.
- Maps 8 x 8 to a 1 x 64 vector



Differential Pulse Code Modulation (DPCM) on DC Component

- Another encoding method is employed
- DPCM on the DC component at least.
- Why is this strategy adopted:
  - DC component is large and varies, but often close to previous value (like lossless JPEG).
  - Encode the difference from previous 8x8 blocks – DPCM

Run Length Encode (RLE) on AC Components

Yet another simple compression technique is applied to the AC component:

- 1x64 vector has lots of zeros in it
- Encode as $(skip, value)$ pairs, where $skip$ is the number of zeros and $value$ is the next non-zero component.
- Send (0,0) as end-of-block sentinel value.

Huffman (Entropy) Coding

DC and AC components finally need to be represented by a smaller number of bits
(Arithmetic coding also supported in place of Huffman coding):

- (Variant of) Huffman coding: Each DPCM-coded DC coefficient is represented by a pair of symbols :
  (`Size`, `Amplitude`)
  where `Size` indicates number of bits needed to represent coefficient and
  `Amplitude` contains actual bits.
- `Size` **only** Huffman coded in JPEG:
  - `Size` does not change too much, generally smaller `Size`s occur frequently (= **low entropy** so is suitable for coding,
  - `Amplitude` can change widely so coding **no real benefit**

Huffman (Entropy) Coding (Cont)

- Example `Size` category for possible `Amplitude`s:

```
 --------------------
Size          Amplitude
0                0
1              -1,1
2            -3,-2,2,3
3            -7..-4,4..7
4           -15..-8,8..15
.                .
.                .
  --------------------
```

- Use *ones complement* scheme for negative values: *i.e* 10 is binary for 2 and 01 for -2.

Huffman Coding DC Example

- *Example*: if DC values are 15,-6, 5,3,-8
- Then 8,3,3, 2 and 4 bits are needed respectively.
  Send off `Size`s as Huffman symbol, followed by actual values in bits.

  $$(8_{huff}, 10010110), (-6_{huff}, 001), (5_{huff}, 101), (3_{huff}, 11), (4_{huff}, 0111)$$

  where $8_{huff}\ldots$ are the Huffman codes for respective numbers.
- Huffman Tables can be custom (sent in header) or default.

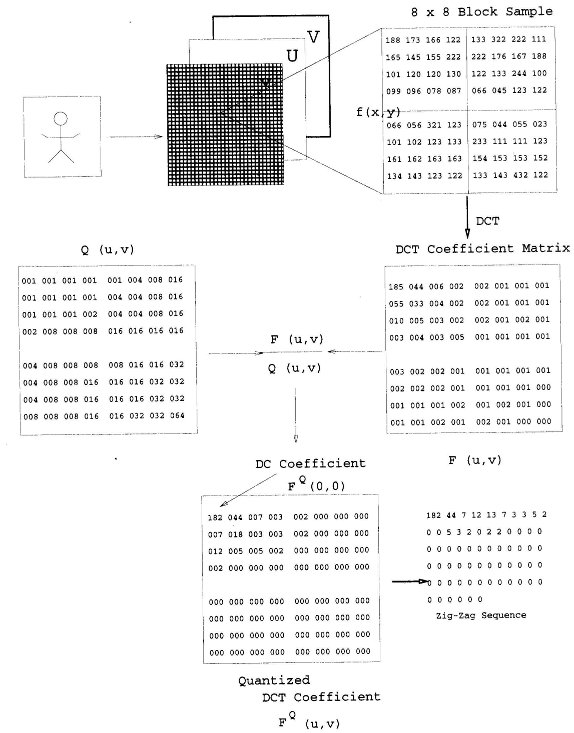
Huffman Coding on AC Component

AC coefficient are **run-length encoded (RLE)**

- RLE pairs (`Runlength`, `Value`) are Huffman coded as with DC **only** on `Value`.
- So we get a triple: (`Runlength`, `Size`, `Amplitude`)
- However, `Runlength`, `Size` allocated 4-bits each and put into a single byte with is then **Huffman coded**.
  Again , `Amplitude` is **not** coded.
- So only two symbols transmitted per RLE coefficient:

$$(\mathtt{RLESIZEbyte}_{huff}, \mathtt{Amplitude})$$

Example JPEG Compression



Another Enumerated Example

139	144	149	153	155	155	155	155
144	151	153	156	159	156	156	156
150	155	160	163	158	156	156	156
159	161	162	160	160	159	159	159
159	160	161	162	162	155	155	155
161	161	161	161	160	157	157	157
162	162	161	163	162	157	157	157
162	162	161	161	163	158	158	158

(a) source image samples

235.6	-1.0	-12.1	-5.2	2.1	-1.7	-2.7	1.3
-22.6	-17.5	-6.2	-3.2	-2.9	-0.1	0.4	-1.2
-10.9	-9.3	-1.6	1.5	0.2	-0.9	-0.6	-0.1
-7.1	-1.9	0.2	1.5	0.9	-0.1	0.0	0.3
-0.6	-0.8	1.5	1.6	-0.1	-0.7	0.6	1.3
1.8	-0.2	1.6	-0.3	-0.8	1.5	1.0	-1.0
-1.3	-0.4	-0.3	-1.5	-0.5	1.7	1.1	-0.8
-2.6	1.6	-3.8	-1.8	1.9	1.2	-0.6	-0.4

(b) forward DCT coefficients

16	11	10	16	24	40	51	61
12	12	14	19	26	58	60	55
14	13	16	24	40	57	69	56
14	17	22	29	51	87	80	62
18	22	37	56	68	109	103	77
24	35	55	64	81	104	113	92
49	64	78	87	103	121	120	101
72	92	95	98	112	100	103	99

(c) quantization table

15	0	-1	0	0	0	0	0
-2	-1	0	0	0	0	0	0
-1	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

(d) normalized quantized coefficients

240	0	-10	0	0	0	0	0
-24	-12	0	0	0	0	0	0
-14	-13	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

(e) denormalized quantized coefficients

144	146	149	152	154	156	156	156
148	150	152	154	156	156	156	156
155	156	157	158	158	157	156	155
160	161	161	162	161	159	157	155
163	163	164	163	162	160	158	156
163	164	164	164	162	160	158	157
160	161	162	162	162	161	159	158
158	159	161	161	162	161	159	158

(f) reconstructed image samples

JPEG Example MATLAB Code

The JPEG algorithm may be summarised as follows,
im2jpeg.m (Encoder) jpeg2im.m (Decoder)
mat2huff.m (Huffman coder)

```
m = [16 11  10  16  24  40  51  61         % JPEG normalizing array
     12  12  14  19  26  58  60  55        % and zig-zag redordering
     14  13  16  24  40  57  69  56        % pattern.
     14  17  22  29  51  87  80  62
     18  22  37  56  68  109 103 77
     24  35  55  64  81  104 113 92
     49  64  78  87  103 121 120 101
     72  92  95  98  112 100 103 99] * quality;

order = [1 9  2  3  10 17 25 18 11 4  5  12 19 26 33  ...
        41 34 27 20 13 6  7  14 21 28 35 42 49 57 50  ...
        43 36 29 22 15 8  16 23 30 37 44 51 58 59 52  ...
        45 38 31 24 32 39 46 53 60 61 54 47 40 48 55  ...
        62 63 56 64];

[xm, xn] = size(x);                  % Get input size.
x = double(x) - 128;                 % Level shift input
t = dctmtx(8);                       % Compute 8 x 8 DCT matrix

% Compute DCTs of 8x8 blocks and quantize the coefficients.
y = blkproc(x, [8 8], 'P1 * x * P2', t, t');
y = blkproc(y, [8 8], 'round(x ./ P1)', m);
```

```
y = im2col(y, [8 8], 'distinct');  % Break 8x8 blocks into columns
xb = size(y, 2);                   % Get number of blocks
y = y(order, :);                   % Reorder column elements

eob = max(y(:)) + 1;               % Create end-of-block symbol
r = zeros(numel(y) + size(y, 2), 1);
count = 0;
for j = 1:xb                       % Process 1 block (col) at a time
   i = max(find(y(:, j)));         % Find last non-zero element
   if isempty(i)                   % No nonzero block values
      i = 0;
   end
   p = count + 1;
   q = p + i;
   r(p:q) = [y(1:i, j); eob];      % Truncate trailing 0's, add EOB,
   count = count + i + 1;          % and add to output vector
end

r((count + 1):end) = [];           % Delete unused portion of r

y           = struct;
y.size      = uint16([xm xn]);
y.numblocks = uint16(xb);
y.quality   = uint16(quality * 100);
y.huffman   = mat2huff(r);
```

Further Information

Basic JPEG Information:

- http://www.jpeg.org
- Online JPEG Tutorial