Week 13

JPEG Compression

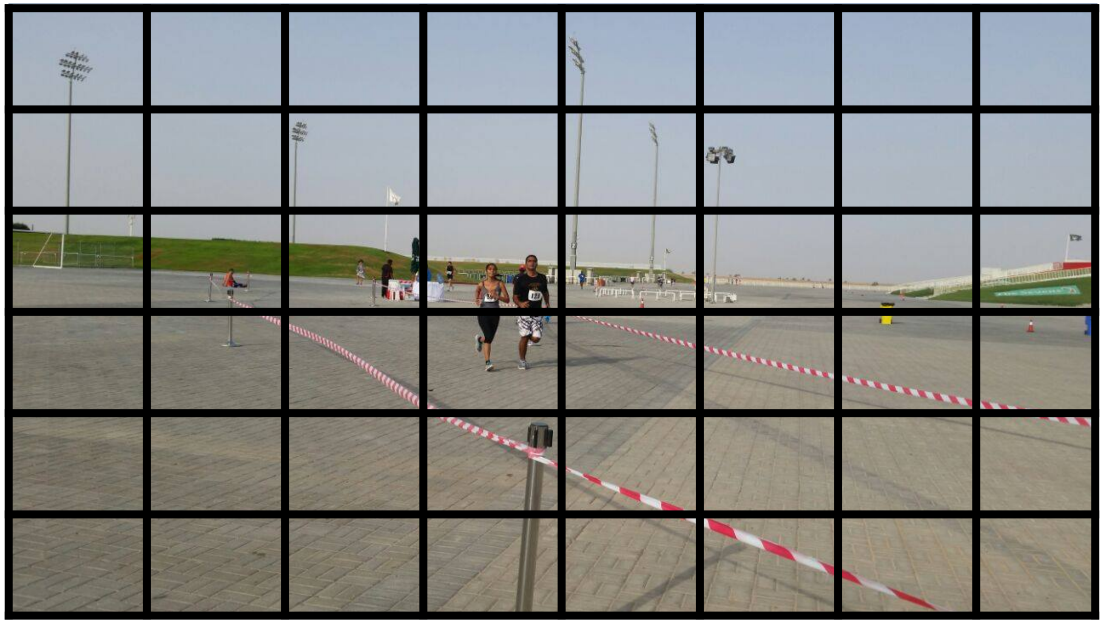
Reference and Slide Source: ChengXiang Zhai and Sean Massung. 2016. Text Data Management and Analysis: a Practical Introduction to Information Retrieval and Text Mining. Association for Computing Machinery and Morgan & Claypool, New York, NY, USA.

Lossy Compression

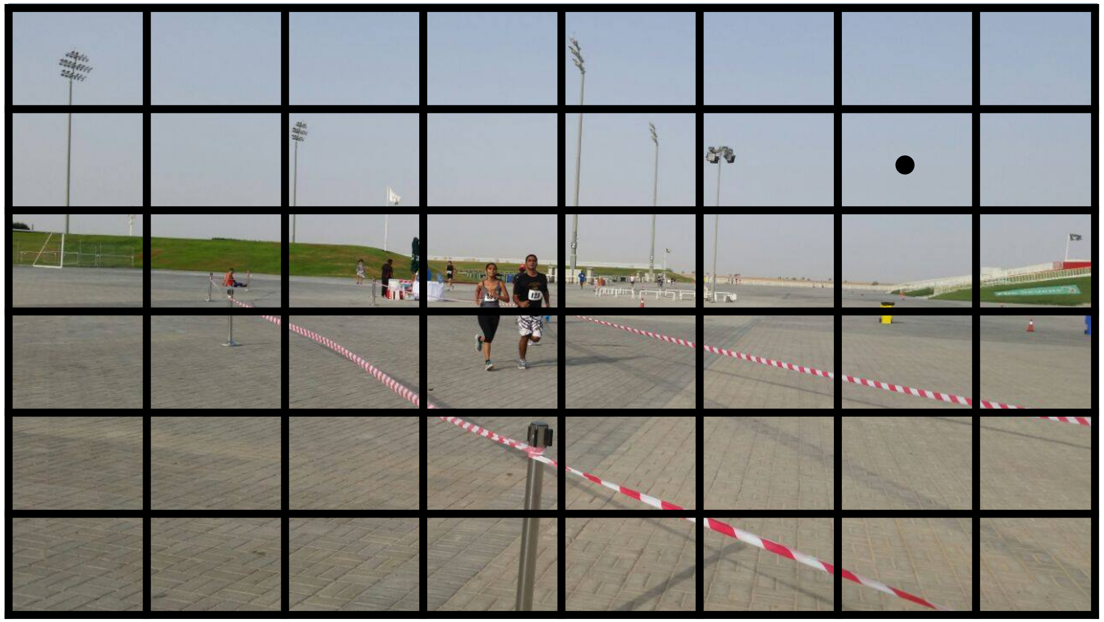
- It causes non-recoverable information loss
- Choose the information we can “afford” to loose without affecting the application

Data: RGB Image
Application: Viewing

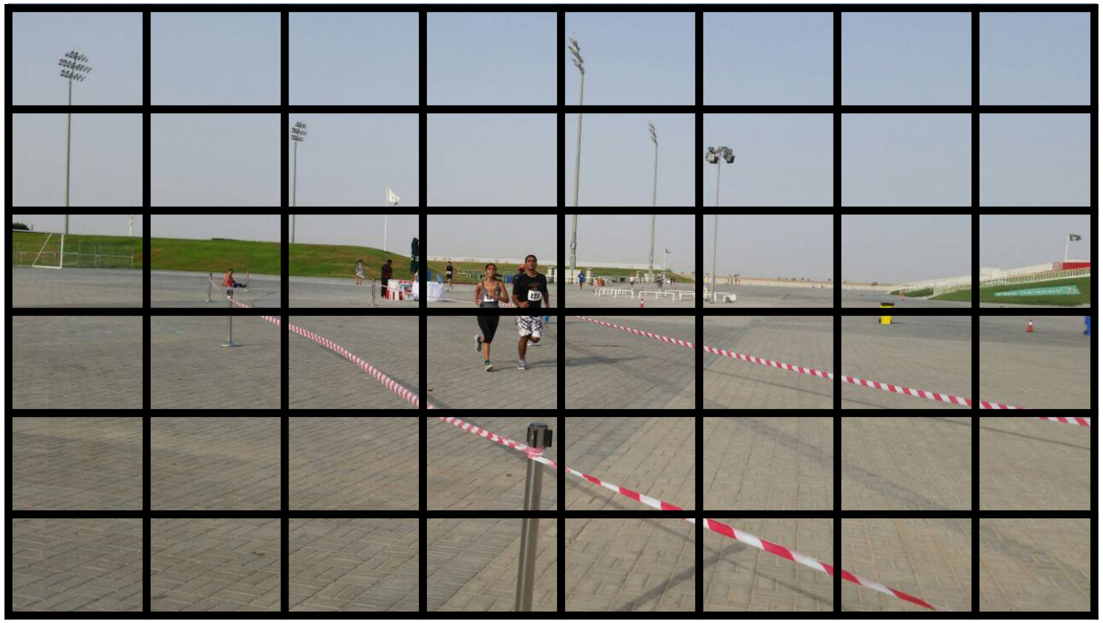
Observation 1: Lesser visual acuity for color – Color redundancy



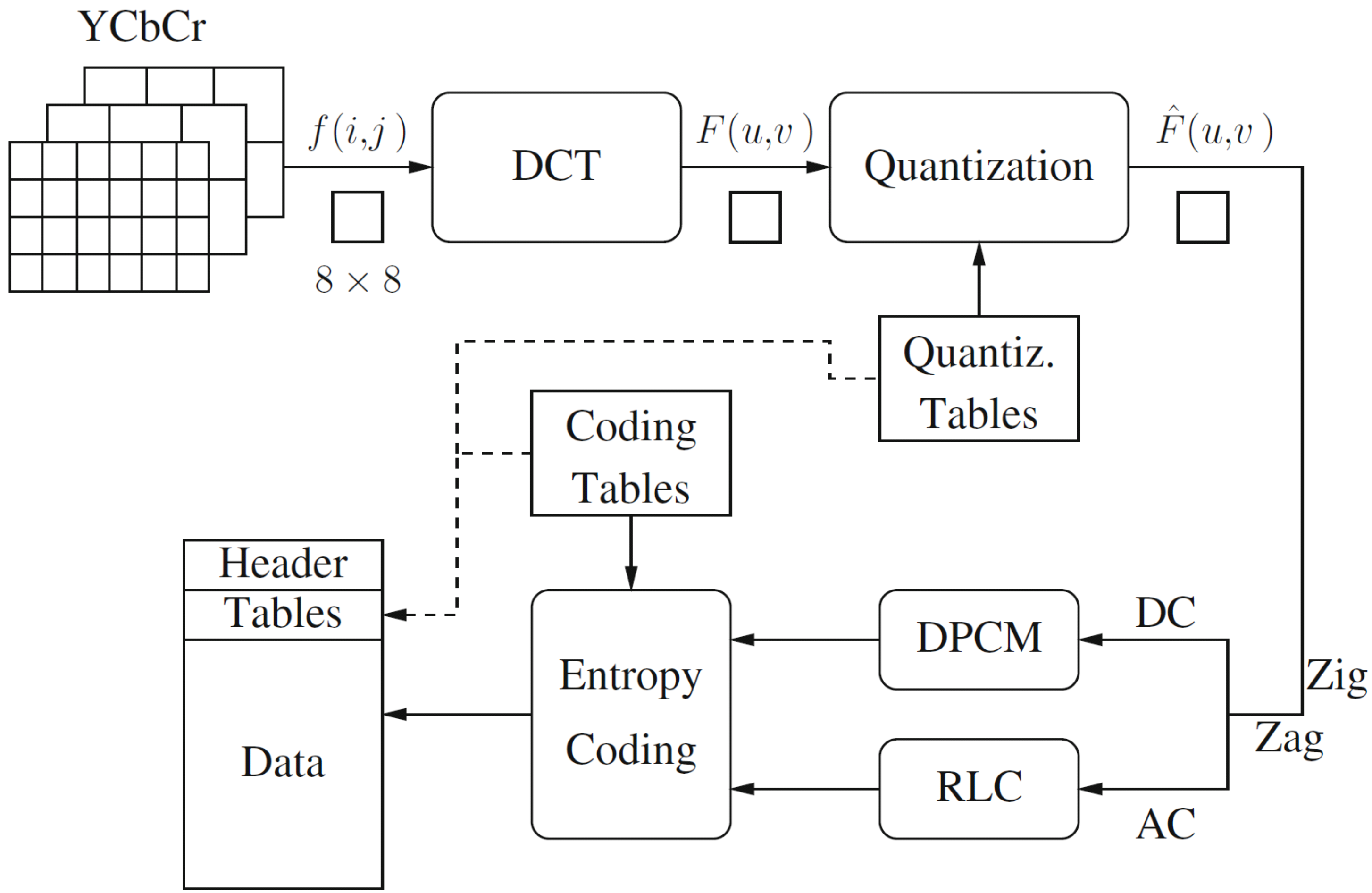
Observation 2: Slow changes - spatial redundancy



Observation 3: Lesser sensitivity to high spatial frequency- spectral redundancy



JPEG Encoder



JPEG Image Compression Steps

- Transform RGB to YCbCr
- Subsample color images – 4:2:2 or 4:2:0
- DCT on image blocks
- Quantization
- Zig-zag ordering and run-length encoding
- Entropy coding

DCT on image blocks

- Each image is divided into 8 × 8 blocks. The 2D DCT is applied to each block image f(i, j), with output being the DCT coefficients F(u, v) for each block.
- Using blocks, however, has the effect of isolating each block from its neighboring context. This is why JPEG images look choppy ("blocky") when a high compression ratio is specified by the user.

Quantization

$$\hat{F}(u,v) = round\left(\frac{F(u,v)}{Q(u,v)}\right)$$

- ***F(u, v)*** represents a DCT coefficient, ***Q(u, v)*** is a "quantization matrix" entry, and $\hat{F}(u,v)$ represents the *quantized DCT coefficients* which JPEG will use in the succeeding entropy coding.
- The quantization step is the main source for loss in JPEG compression.
- The entries of ***Q(u, v)*** tend to have larger values towards the lower right corner. This aims to introduce more loss at the higher spatial frequencies

Quantization Tables

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

Luminance

17	18	24	47	99	99	99	99
18	21	26	66	99	99	99	99
24	26	56	99	99	99	99	99
47	66	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99
99	99	99	99	99	99	99	99

Chrominance

An 8 × 8 block from the Y image of 'Lena'

200	202	189	188	189	175	175	175
200	203	198	188	189	182	178	175
203	200	200	195	200	187	185	175
200	200	200	200	197	187	187	187
200	205	200	200	195	188	187	175
200	200	200	200	200	190	187	175
205	200	199	200	191	187	187	175
210	200	200	200	188	185	187	186

f(i, j)

515	65	-12	4	1	2	-8	5
-16	3	2	0	0	-11	-2	3
-12	6	11	-1	3	0	1	-2
-8	3	-4	2	-2	-3	-5	-2
0	-2	7	-5	4	0	-1	-4
0	-3	-1	0	4	1	-1	0
3	-2	-3	3	3	-1	-1	3
-2	5	-2	4	-2	2	-3	0

F(u, v)

JPEG compression of a smooth image block

32	6	−1	0	0	0	0	0
−1	0	0	0	0	0	0	0
−1	0	1	0	0	0	0	0
−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

$\hat{F}(u, v)$

512	66	−10	0	0	0	0	0
−12	0	0	0	0	0	0	0
−14	0	16	0	0	0	0	0
−14	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

$\tilde{F}(u, v)$

199	196	191	186	182	178	177	176
201	199	196	192	188	183	180	178
203	203	202	200	195	189	183	180
202	203	204	203	198	191	183	179
200	201	202	201	196	189	182	177
200	200	199	197	192	186	181	177
204	202	199	195	190	186	183	181
207	204	200	194	190	187	185	184

$\tilde{f}(i, j)$

1	6	−2	2	7	−3	−2	−1
−1	4	2	−4	1	−1	−2	−3
0	−3	−2	−5	5	−2	2	−5
−2	−3	−4	−3	−1	−4	4	8
0	4	−2	−1	−1	−1	5	−2
0	0	1	3	8	4	6	−2
1	−2	0	5	1	1	4	−6
3	−4	0	6	−2	−2	2	2

$(i, j) = f(i, j) - \tilde{f}(i, j)$

JPEG compression of a smooth image block

Another 8 × 8 block from the Y image of 'Lena'

70	70	100	70	87	87	150	187
85	100	96	79	87	154	87	113
100	85	116	79	70	87	86	196
136	69	87	200	79	71	117	96
161	70	87	200	103	71	96	113
161	123	147	133	113	113	85	161
146	147	175	100	103	103	163	187
156	146	189	70	113	161	163	197

f(i, j)

-80	-40	89	-73	44	32	53	-3
-135	-59	-26	6	14	-3	-13	-28
47	-76	66	-3	-108	-78	33	59
-2	10	-18	0	33	11	-21	1
-1	-9	-22	8	32	65	-36	-1
5	-20	28	-46	3	24	-30	24
6	-20	37	-28	12	-35	33	17
-5	-23	33	-30	17	-5	-4	20

F(u, v)

JPEG compression of a textured image block

−5	−4	9	−5	2	1	1	0
−11	−5	−2	0	1	0	0	−1
3	−6	4	0	−3	−1	0	1
0	1	−1	0	1	0	0	0
0	0	−1	0	0	1	0	0
0	−1	1	−1	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

$\hat{F}(u, v)$

−80	−44	90	−80	48	40	51	0
−132	−60	−28	0	26	0	0	−55
42	−78	64	0	−120	−57	0	56
0	17	−22	0	51	0	0	0
0	0	−37	0	0	109	0	0
0	−35	55	−64	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

$\tilde{F}(u, v)$

70	60	106	94	62	103	146	176
85	101	85	75	102	127	93	144
98	99	92	102	74	98	89	167
132	53	111	180	55	70	106	145
173	57	114	207	111	89	84	90
164	123	131	135	133	92	85	162
141	159	169	73	106	101	149	224
150	141	195	79	107	147	210	153

$\tilde{f}(i, j)$

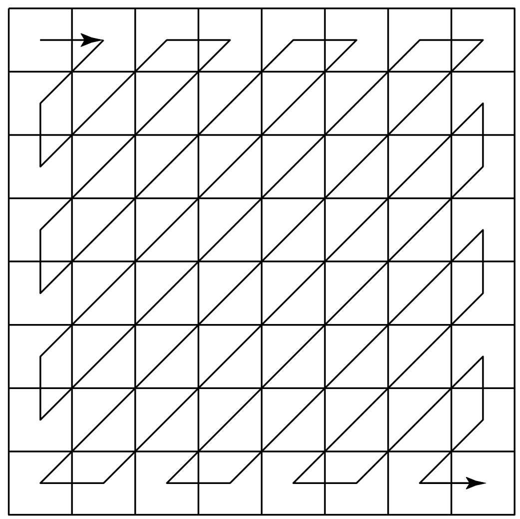
0	10	−6	−24	25	−16	4	11
0	−1	11	4	−15	27	−6	−31
2	−14	24	−23	−4	−11	−3	29
4	16	−24	20	24	1	11	−49
−12	13	−27	−7	−8	−18	12	23
−3	0	16	−2	−20	21	0	−1
5	−12	6	27	−3	−2	14	−37
6	5	−6	−9	6	14	−47	44

$(i, j) = f(i, j) - \tilde{f}(i, j)$

JPEG compression for a textured image block.

Run-length Coding (RLC) on AC coefficients

- RLC aims to turn the $\hat{F}(u,v)$ values into sets *{#-zeros-to-skip, next non-zero value*}.
- To make it most likely to hit a long run of zeros: a *zig-zag scan* is used to turn the 8×8 matrix $\hat{F}(u,v)$ into a *64-vector*.



DPCM on DC coefficients

- The DC coefficients are coded separately from the AC ones. *Differential Pulse Code modulation* (*DPCM*) is the coding method.

- If the DC coefficients for the first 5 image blocks are 150, 155, 149, 152, 144, then the DPCM would produce 150, 5, -6, 3, -8, assuming $d_i = DC_{i+1} - DC_i$, and $d_0 = DC_0$.

Entropy Coding

- The DC and AC coefficients finally undergo an entropy coding step to gain a possible further compression.
- Use DC as an example: each DPCM coded DC coefficient is represented by (SIZE, AMPLITUDE), where SIZE indicates how many bits are needed for representing the coefficient, and AMPLITUDE contains the actual bits.
- In the example we're using, codes 150, 5, −6, 3, −8 will be turned into
  - (8, 10010110), (3, 101), (3, 001), (2, 11), (4, 0111) .
- SIZE is Huffman coded since smaller SIZEs occur much more often. AMPLITUDE is not Huffman coded, its value can change widely so Huffman coding has no appreciable benefit.

Baseline entropy coding details – size category.

SIZE	AMPLITUDE
1	-1, 1
2	-3, -2, 2, 3
3	-7..-4, 4..7
4	-15..-8, 8..15
.	.
.	.
.	.
10	-1023..-512, 512..1023

JPEG Modes for Internet!

Progressive Mode

Delivers low quality versions of the image quickly, followed by higher quality passes!

Progressive Mode - Spectral selection

- Scan 1: Encode DC and first few AC components, e.g., AC1, AC2.
- Scan 2: Encode a few more AC components, e.g., AC3, AC4, AC5.
- ...
- Scan k: Encode the last few ACs, e.g., AC61, AC62, AC63.

Takes advantage of the "spectral" (spatial frequency spectrum) characteristics of the DCT coefficients: higher AC components provide detail information.

Progressive Mode - Successive approximation

- Scan 1: Encode the first few MSBs, e.g., Bits 7, 6, 5, 4.
- Scan 2: Encode a few more less significant bits, e.g., Bit 3.
- ...
- Scan m: Encode the least significant bit (LSB), Bit 0.

Instead of gradually encoding spectral bands, all DCT coefficients are encoded simultaneously but with their most significant bits (MSBs) first.

Hierarchical Mode

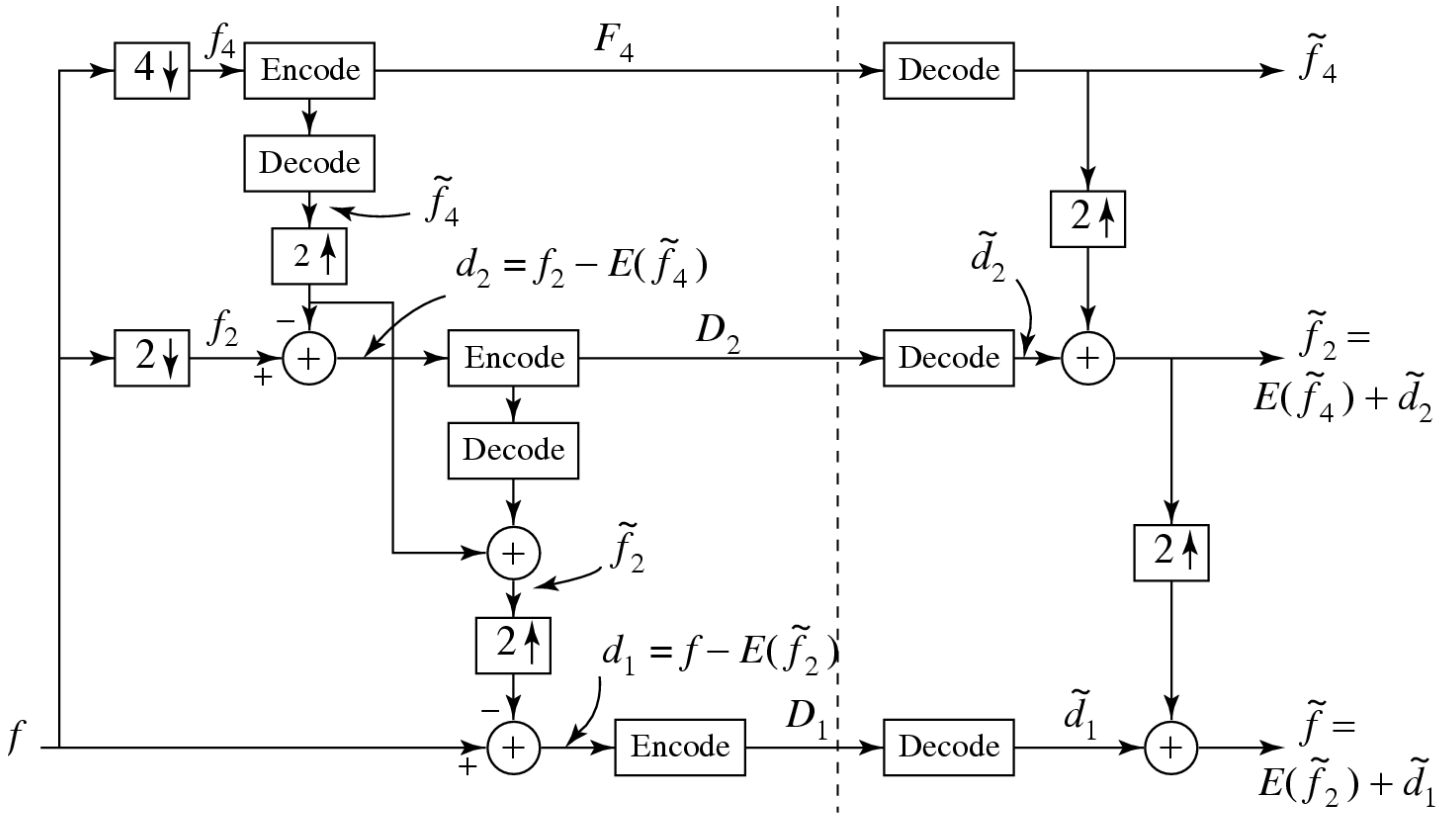
Encode low resolution image followed by additional details to construct high resolution!

Hierarchical Mode

- The encoded image at the lowest resolution is basically a compressed low-pass filtered image, whereas the images at successively higher resolutions provide additional details (differences from the lower resolution images).

- Similar to Progressive JPEG, the Hierarchical JPEG images can be transmitted in multiple passes progressively improving quality.

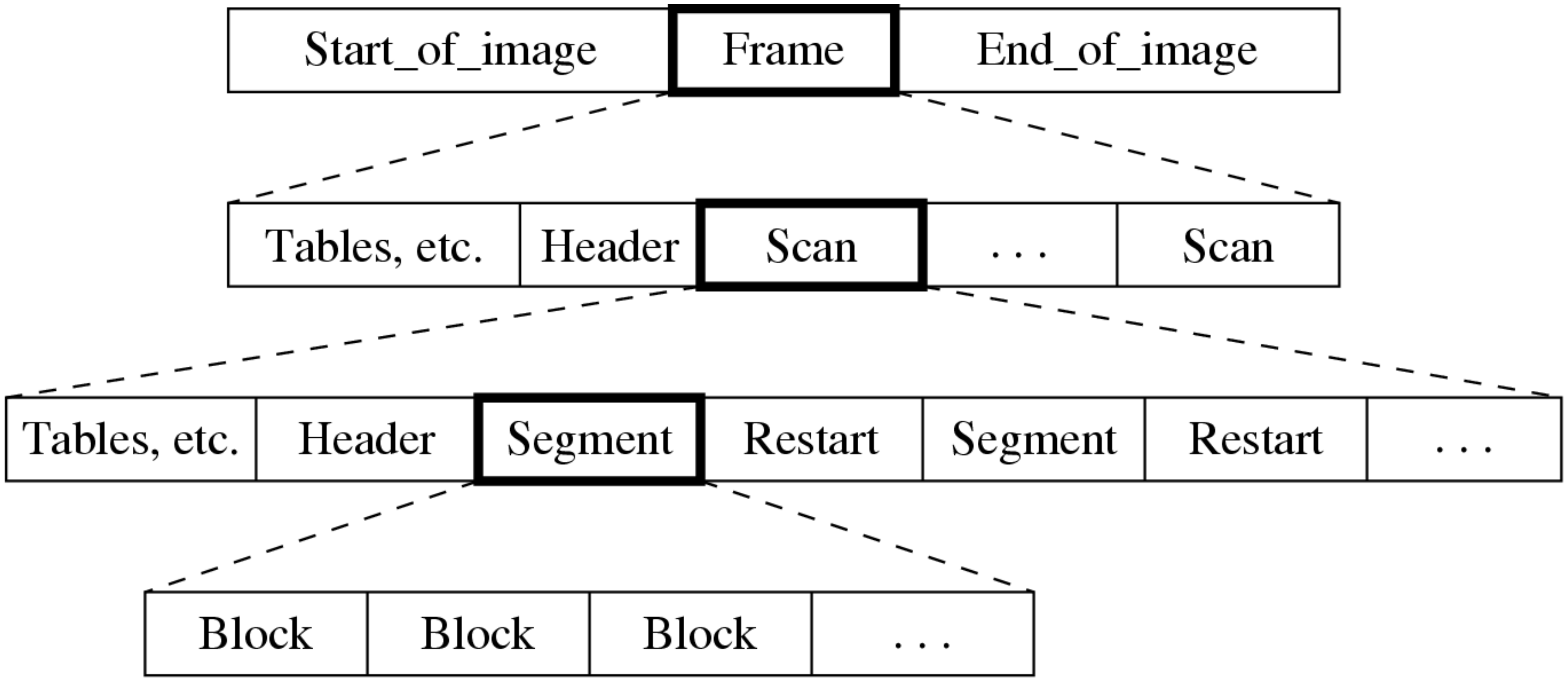
Block diagram for Hierarchical JPEG



Four Commonly Used JPEG Modes

1. Sequential Mode (default)
2. Progressive Mode.
3. Hierarchical Mode.
4. Lossless Mode

JPEG bitstream



Frame header: Bits per pixel, width, height, quantization table, etc.
Scan header: Huffman table, number of components, etc.