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EEE116 – Multimedia Systems
Tutorial problems

(Q1) (a) Consider the analogue signal

$$x(t) = 3\cos(2000t)+5\sin(6000t)-10\cos(12000t)$$

What is the Nyquist rate of this signal?

(b) How many different symbols can be represented using a 16 bit digital code?

(c) The human eye can perceive 15,000 different colours. How many bits are required to represent the full range of colours?

(d) An alien species can perceive only half of the colours that the humans can perceive. How many bits can be saved when the colour range of aliens' visual system is represented in digital form compared to that of the humans?

(Q2) The output from a microphone to record the sonic pulses emitted by bats can be at frequencies up to 50 kHz and up to 1 V in amplitude.

(a) What is the minimum time of the sampling period of an analogue-to-digital recorder in order to be able to reproduce faithfully these signals?

(b) If we wish to record changes in the signal amplitude as small as 1 mV, how many bits will be needed to represent these signals in a digital memory?

(c) You have a 64 M byte flash memory stick, how many minutes of bat recordings can you store?

(Q3) Estimate the maximum uncorrupted data rate, in bits/s, for the following communication link:

Bandwidth = 12 MHz
Signal power = 100 mW
Noise power = 20 μW

What is the signal-to-noise power ratio in dB?

As an engineer, you are asked to improve this link – which is best (i) to double the bandwidth, or (ii) to double the signal power?

(Q4) You have a 160 G Byte hard disc – full of important data – that needs to be transferred to a computer in London. Assume that the distance between London and Sheffield is 250km and the effective speed of light is $3\text{x}10^8$ ms^{-1}.

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Estimate the time it will take to transfer all this data, if you use:

b. A conventional phone line with a normal modem attached (assume that the modem can send 20 Kbits/s),
c. A high speed computer network link with a bandwidth of 10 MHz, (assume that you can send one bit of information per period)
d. A direct optical link using light at a wavelength of 0.7 μm (i.e., red light) (assume that you can send one bit of information per period and no limitations due to the electronic systems at either end of the link) and
e. The train?

(Q5) In the process of sampling an analogue signal to convert it to digital formats, the following set of voltage values was measured. (Read from left to right and top to bottom. We call it Raster scan)

-2	0	1	1	0	2	-1	0	1	2
-1	-1	0	2	0	1	0	0	0	-1
0	1	1	1	0	-1	2	1	-1	0
0	3	0	-1	0	1	0	-1	0	1
-1	0	1	0	3	1	-1	0	-2	0

(i) Fill in the following table

Sample value	-2	-1	0	1	2	3
Number of samples						

(ii) Devise a digital code to represent these sample values in digital form.

(iii) Compute the total number of bits required to represent these samples in digital format.

(iv) What is the average number code length for the digital code devised in (ii)?

(v) We call the codes like in (ii) “fixed length codes”, as each sample is represented by a fixed number of bits. Now consider a “variable length code” as shown in the following table.

Sample value	-2	-1	0	1	2	3
Digital code	1110	110	0	10	11110	11111

Compute the average code length if the above variable length code is used.

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(vi) How many bits can be saved (in total) by using the variable length code compared to the fixed length code in (ii)?

(vii) Decode the following bit stream which has been generated using the variable length code in (v).

101111001101110110010101111110.

(viii) If the 8th and 9th bits in the bit stream in (vii) were corrupted and were unable to recover accurately, what would be the decoded sample values?

(Q6) An information source outputs 5 different symbols {$, %, &, @, £} with probabilities {0.5, 0.25, 0.125, 0.0625, 0.0625}, respectively. The following table shows 4 different codes (1 fixed length binary code and 3 variable length codes) that can be used for this alphabet.

Symbol	Probability	Code1	Code2`	Code3	Code4
A	1/2	000	1	0	00
B	1/4	001	01	10	01
C	1/8	010	001	110	10
D	1/16	011	0001	1110	11
E	1/16	111	00001	1111	110

(i) Compute the average code length for above 4 codes?
(ii) In an unambiguous code, no codeword is the prefix of another codeword. Which of the above codes are unambiguous?

(Q7) Derive the Huffman code for the following message:

A E B A B D A A C D C D A A B C E A E A A B B D A A C A E D B A A C A E D C B

Calculate the average code length and compare with Shannon's Entropy value.

If the data was originally coded using fixed length binary codes, what compression ratio would be achieved by using the derived Huffman Coding?

(Q8) A 25-value of data set is shown below.

17 17 17 18 18 17 16 16 16 16 16 17 18 19 19 19 19 20 20 20 20 20 19 18 18

(i) Compute the Shannon's entropy value for the data set.

(ii) The data is first represented in digital format using fixed length codes. How many bits are required for a codeword using the fixed length code?

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(iii) A simple lossless compression model is used for reduction of the average code lengths. A simple lossless compression model consists of DPCM followed by the Huffman coding. Derive the DPCM of this data set. What is the Shannon's entropy value for the new data set? How much compression is achieved by the DPCM process?

(iv) Devise the Huffman code for the new data set.

(v) What is the efficiency of the devised Huffman code?

(vi) Estimate the inter-sample redundancy and the coding redundancy removed by the DPCM and Huffman coding, respectively?

(vii) What is the overall compression ratio?

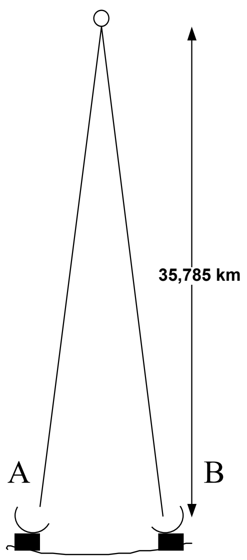
(Q9) An audio signal containing 3 large amplitude frequency components at frequencies 5kHz, 10kHz and 20kHz is sampled at the Nyquist rate into 6 distinct voltage levels as follows:

{-2, -1, 0, 1, 2, 3}. The corresponding probabilities of occurrence for these voltage values are {0.4, 0.06, 0.08, 0.12, 0.25, 0.09}, respectively.

(a) Draw a block diagram of a system for digitising this audio signal and specify the parameter values used for the main components of the system. (Assume that the capturing device adds +/- 1 mV noise to the signal at the time of capturing).

(b) If the signal is encoded using Huffman coding, estimate the time to send a recording of 5 minutes of this signal to a destination at 300 km distance via a link with bandwidth of 10 MHz and an SNR of 20 dB.

(Q.10)



How long would it take to send a 3 minute long CD-quality stereo (2-channels) audio bit stream recorded using 44.1 kHz sampling rate and 16 bits representation from A to B using a geosynchronous satellite link ?

Assume 256 kbps link to and from the satellite, and that the satellite takes 50 ms to receive and then retransmit a signal. Speed of light is 3 x 10^8 ms^{-1}.

What would be the effect on the audio quality and the total time taken to reach the destination, if 8 bits per sample quantisation was used instead of 16 bits per sample?

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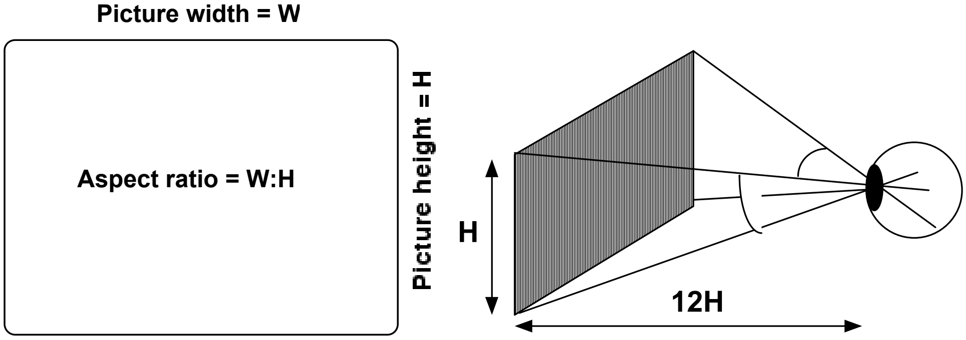
(Q11) The aim of this exercise is to estimate the required resolution for television and computer displays that their appearance matches our own visual abilities.

We know that we can detect fine spatial details in an image up to 60 cycles/degree subtended to the eye (in both horizontal and vertical directions. We can also detect temporal changes in an image up to 70 Hz (the flicker rate). We can detect up to about 100 different grey levels at one time in a monochrome image and up to about 50,000 different colours (hues) in a colour image.

(i) Estimate the resolution (in pixels (picture elements) of a static display if it is to give the impression of a high-quality, continuous image. The aspect ratio is the display screen is 4:3 (that is ratio of picture width to picture height). Assume that we sit, on average 12 times the picture height in front of the display screen. (Remember the Nyquist Criterion)



(ii) Estimate the computer memory requirements (in bits) to hold (a) one monochrome screen, and (b) one full colour screen.

(iii) Estimate the total memory requirements to store one hour of video to played in full colour at the screen resolution determined in (i) above, the changing display is to appear as smooth continuous motion to us. (Remember the Nyquist Criterion).

(iv) How do the above estimates compare with the actual screen resolution of practical displays and the total memory capacity of a DVD disc? Comment on your answers.

(v) If the available bandwidth is premium and the Nyquist limit can be relaxed, revisit (i) and (iii) and define the new spatial and temporal resolutions. What is the new data rate?

(Q12) HDTV sequences consist of RGB 4:4:4 format video with 1920x1088 spatial resolution, 10 bit depth for each of three colours and 50 frames per second frame rate.

(i) Compute the data rate of an uncompressed HDTV sequence.

(ii) What percentage of data rate can be reduced by using YCbCr 4:2:0 format, instead of RGB 4:4:4?

(iii) How much disk space would it take to store a 1-hour HDTV programme in the uncompressed YCbCr 4:2:0 format?

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(Q13) A 16x16 block of an 8-bit luminance image contains 8 gray level values. Their frequencies of occurrence are as follows:

Gray level	Frequency of occurrence
125	8
131	32
134	128
135	64
139	16
141	4
144	2
150	2

(i) Compute the coding redundancy of this image block.

(ii) How much compression can be achieved by using Huffman code to represent these pixel values? (Compute your answer without deriving the Huffman codes).

(iii) In order to further compress this image block, you decided to quantise the gray values using a quantisation factor Q=8.

a. Now derive the new frequencies of occurrence for the quantised values.

b. Compute the new entropy value.

c. Derive the Huffman code for the new symbols.

d. Compute the compression ratio achieved by combined quantisation and entropy (Huffman) encoding.

(Q14) Gray level values of an 8-bit 4x2 image are shown below. You have been asked to reduce the colour depth resolution of this image.

251	234	155	191
241	211	171	111

(i) What quantisation factor would you use if you had to reduce the colour depth to 5 bits?

(ii) Compute the reconstructed (quantised and de-quantised) image for the above case.

(iii) What is the PSNR (Peak Signal to Noise Ratio) of the reconstructed image?

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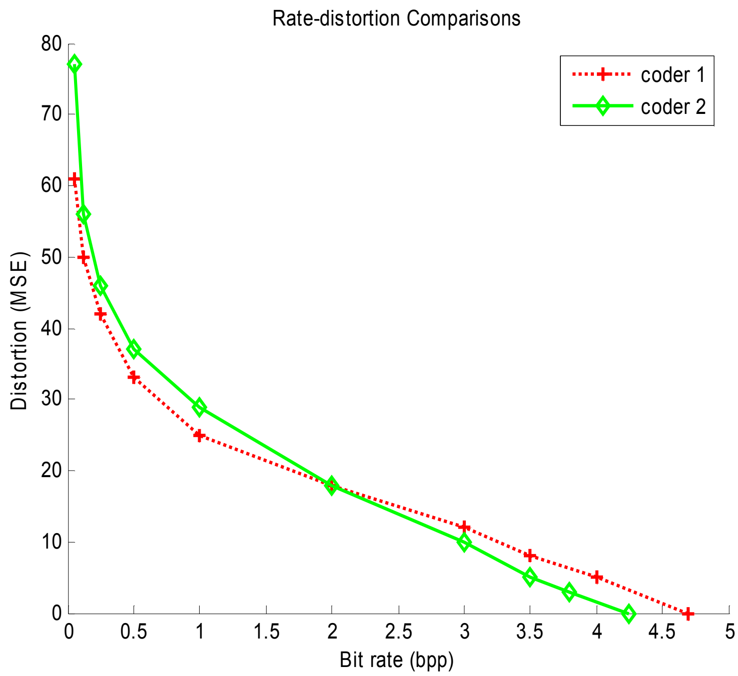
(Q15)



Rate-distortion plots for two image coders using an 8 bpp image are shown in the figure.

(i) Compute the lossless compression ratio for each codec and comment on their efficiency.
(ii) Compute the PSNR values for the two codecs when a compression ratio of 8:1 is used.
(iii) Which codec performs better for compressing images to a high compression ratio?

(Q16) An SDTV resolution YUV 4:2:2 @ 30 fps video sequence is encoded using the MPEG-2 standard with a Group of Picture (GOP) size of 9 pictures. The coding scheme uses 2 B frames between 2 consecutive P frames.

(i) Compute the data rate of the uncompressed video sequence
(ii) What is the I-B-P coding structure used in this specification?
(iii) If the compression ratios obtained for I, P and B frames (including motion vector and prediction error coding) are 20:1, 40:1 and 80:1, respectively, what is the bit rate of the compressed video?

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(Q17)

Try this exercise before the tutorial – you will need the data
On any Windows PC

1. From the **Start** menu, select **Run...**
2. In the **Run** dialog box, type cmd and press **<<Enter>>** .
3. At the command line, type ping www.cam.ac.uk
4. After you typing the ping command, you will get a message that looks like:

```
U:\>ping www.cam.ac.uk
Pinging www.cam.ac.uk [131.111.8.46] with 32 bytes of data:

Reply from 131.111.8.46: bytes=32 time=10ms TTL=247
Reply from 131.111.8.46: bytes=32 time=10ms TTL=247
Reply from 131.111.8.46: bytes=32 time=9ms TTL=247
Reply from 131.111.8.46: bytes=32 time=9ms TTL=247

Ping statistics for 131.111.8.46:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 9ms, Maximum = 10ms, Average = 9ms
```

The time is the round-trip time (RTT) to send a small packet to the specified address and for its return. From the above example (yours may look slightly different) the average time to send and get back these packets is 9 ms.

- Use *ping* record the RTTs for a local address (e.g., www.sheffield.ac.uk), then a UK address (e.g., www.bbc.co.uk), and finally a distant address (e.g., www.usyd.edu.au). Explain the differences in RTTs. What effect is there on RTTs if you carry out this small experiment at different times of the day?
- For a USA address (e.g., www.princeton.edu) find the RTTs and then estimate the minimum theoretical RTT. Assume that the RTT is dominated by the time to send a signal over the Atlantic via a geostationary satellite. How does this compare with practical values?

  For this calculation, you will need to know that geostationary satellites are about 36,000 km above the earth's surface, width of the Atlantic is some 5,500 km and speed of light is 3×10^8 ms^{-1}.

  The TTL field (originally stood for *time-to-live*) tells you how many hops (routing nodes) the message has passed through. It starts at 255 and is decremented by 1 at every hop. What does this tell you about the Internet?

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(Q18)

Calculate the total time required to transfer a 1000 Kbyte file in the following three cases: Assume in all three cases that the Round Trip Time (RTT) is 100 ms, the packet size is 1 Kbyte and that initial handshaking takes place before the data is sent (This handshaking takes the equivalent of 2 x RTT).

i) A link bandwidth of 1.5 Mbps and data packets can be sent continuously

ii) A bandwidth of 1.5 Mbps but after sending each packet wait one RTT before sending the next

iii) The bandwidth is infinite (i.e., transmit time is zero) and up to 20 packets can be sent per RTT.

(Q19)

Visit http://www.net.cmu.edu/cgi-bin/netops.cgi and run traceroute command for www.shef.ac.uk. This command will trace the route from www.cmu.edu to www.shef.ac.uk and will display all the hops involved in reaching the destination. An example route when I ran the experiment is show below.

```
traceroute to garuda.shef.ac.uk (143.167.2.73), 30 hops max, 38 byte packets
 1  POD-C-VL4.GW.CMU.NET (128.2.4.1)  0.246 ms  0.203 ms  0.186 ms
 2  CORE255-VL907.GW.CMU.NET (128.2.255.186)  0.277 ms  0.191 ms  0.185 ms
 3  POD-I-CYH-VL942.GW.CMU.NET (128.2.255.205)  0.211 ms  0.200 ms  0.193 ms
 4  bar-cmu-ge-4-0-0-2.3rox.net (192.88.115.185)  0.291 ms  0.273 ms  0.266 ms
 5  beast-bar-pc1-1.3rox.net (192.88.115.77)  0.229 ms  0.164 ms  0.168 ms
 6  abilene-psc.abilene.ucaid.edu (192.88.115.124)  10.079 ms  9.921 ms  9.816 ms
 7  abilene-wash.rt1.fra.de.geant2.net (62.40.125.17)  115.565 ms  115.561 ms  115.565 ms
 8  so-5-0-0.rt1.ams.nl.geant2.net (62.40.112.58)  139.054 ms  122.897 ms  122.920 ms
 9  so-1-0-0.rt1.lon.uk.geant2.net (62.40.112.138)  130.981 ms  130.987 ms  130.998 ms
10  po2-0-0.gn2-gw1.ja.net (62.40.124.198)  131.124 ms  130.882 ms  130.871 ms
11  po1-1.lond-scr3.ja.net (146.97.35.97)  130.902 ms  130.941 ms  130.916 ms
12  po1-0.lond-scr.ja.net (146.97.33.29)  131.145 ms  131.147 ms  131.169 ms
13  po3-0.leed-scr.ja.net (146.97.33.69)  135.590 ms  135.536 ms  136.019 ms
14  po1-0.leeds-bar.ja.net (146.97.35.74)  135.495 ms  135.503 ms  135.511 ms
15  146.97.41.150 (146.97.41.150)  135.727 ms  135.589 ms  135.707 ms
16  garuda.shef.ac.uk (143.167.2.73)  137.238 ms  137.919 ms  137.639 ms
17  garuda.shef.ac.uk (143.167.2.73)  137.242 ms  136.929 ms  137.065 ms
```

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Using the above trace,

a) Find the IP address class in the cmu.net network and the maximum number of hosts connected to this network at any given time.

b) How many hops are required to reach the www.shef.ac.uk from the source?

c) What is the value of the TTL field in the IP datagram, when it reached the destination?

d) What is the average RTT?

e) Why there are 3 time measurements shown for each measurement?

f) What is the IP address of the European gateway?