4. (a) Draw a diagram of the MPEG encoder with the following blocks.

- Discrete Cosine Transform (DCT)
- Inverse Discrete Cosine Transform (IDCT)
- Quantization (Q)
- Inverse Quantization (IQ)
- Motion Estimation (ME)
- Variable Length Coding (VLC)
- Buffer

(a)用下列块绘制MPEG编码器的图。

离散余弦变换（DCT）

逆离散余弦变换（IDCT）

量化(Q)

逆量化（IQ）

运动估计（ME）

可变长度编码（VLC）

缓冲器

(4 Marks)

Note: Question No. 4 continues on page 4.

视频压缩算法（如MPEG）在编码视频帧时使用切片结构。

(i)讨论为什么使用切片结构来编码视频帧。

（ii）给出在视频编码中每帧使用多个切片与每帧使用一个切片的优点和缺点。

(b) Video compression algorithms such as MPEG use the slice structure when encoding a video frame.

(i) Discuss why the slice structure is used to encode a video frame.

(ii) Give an advantage and a disadvantage of using multiple slices per frame as compared with using one slice per frame in video coding.

(6 Marks)

(c) In the MPEG video coding, a Group of Pictures (GOP) structure may contain I-frame, B-frame(s) and P-frame(s). Briefly describe I-frame, B-frame and P-frame in a GOP.

(4 Marks)

在MPEG视频编码中，一组图片（GOP）结构可能包含Iframe、b帧和p帧。
简要描述GOP中的i -框架、b -框架和p -框架。

(d) Huffman coding uses variable length coding in which a bitstream can be uniquely decodable into codewords. The symbols S = {a, b, c, d, e, f} have the corresponding codewords as shown in Table 1. State clearly whether the codewords can be Huffman codewords, and briefly justify your answer.

霍夫曼编码使用可变长度编码，其中比特流可以唯一地解码成码字。
符号S = fa, b, c, d, e, f}对应的码字如表1所示。
清楚地说明码字是否可以是霍夫曼码字，并简要地证明你的答案。

Table 1

S	a	b	c	d	e	f
Codeword	1100	1001	101	111	10	0

(6 Marks)

```
+---------------------+
|  Input Video Frame  |
+----------+----------+
           |
           v
+---------------------+
|  Motion Estimation  |
|        (ME)         |
+----------+----------+
           |
           v
+---------------------+       +---------------------+
|   Motion Vectors    |<------+ Reconstructed Frame |
+----------+----------+       +----------+----------+
           |                             ^
           v                             |
+---------------------+                  |
|  Motion Compensation|                  |
+----------+----------+                  |
           |                             |
           v                             |
+---------------------+                  |
|   Predicted Frame   |------------------+
+----------+----------+
           |
           v
+---------------------+
|    Subtractor (-)   |
+----------+----------+
           |
           v
+---------------------+
|         DCT         |
+----------+----------+
           |
           v
+---------------------+
|   Quantization (Q)  |
+----------+----------+
           |
           v
+---------------------+
|         VLC         |
+----------+----------+
           |
           v
+---------------------+
|        Buffer       |
+----------+----------+
           |
           v
+---------------------+
| Inverse Quantization|
|        (IQ)         |
+----------+----------+
           |
           v
+---------------------+
|        IDCT         |
+----------+----------+
           |
           v
+---------------------+
| Reconstructed Error |
|       Signal        |
+----------+----------+
           |
           v
+---------------------+
|      Adder (+)      |
+----------+----------+
           |
           v
+---------------------+
| Reconstructed Frame |
+---------------------+
```

Explanation of the Diagram:图表说明:

- **Input Video Frame**: The raw video frame enters the encoder.
  输入视频帧：原始视频帧进入编码器。
- **Motion Estimation (ME)**: Compares the current frame with reference frames to estimate motion, generating motion vectors.
  运动估计（ME）：将当前帧与参考帧进行比较以估计运动，生成运动矢量。
- **Motion Compensation**: Uses motion vectors to create a predicted frame.
  运动补偿：使用运动矢量创建预测帧。
- **Subtractor (-)**: Calculates the difference (residual error) between the input frame and the predicted frame.**减法器（-）**：计算输入帧和预测帧之间的差异（残差）。
- **Discrete Cosine Transform (DCT)**: Transforms the residual error from the spatial domain to the frequency domain.**离散余弦变换（DCT）**：将残余误差从空间域变换到频域。
- **Quantization (Q)**: Reduces the precision of the DCT coefficients to achieve compression.
  量化（Q）：降低DCT系数的精度以实现压缩。
- **Variable Length Coding (VLC)**: Encodes the quantized coefficients into a compressed bitstream using entropy coding.
  可变长度编码 (VLC)：使用熵编码将量化系数编码为压缩比特流。
- **Buffer**: Temporarily stores the compressed data to manage bit rate and data flow.
  缓冲区：临时存储压缩数据以管理比特率和数据流。
- **Inverse Quantization (IQ)**: Reconstructs an approximation of the original DCT coefficients.**逆量化 (IQ)**：重建原始 DCT 系数的近似值。
- **Inverse Discrete Cosine Transform (IDCT)**: Converts the coefficients back to the spatial domain, reconstructing the residual error signal.
  逆离散余弦变换 (IDCT)：将系数转换回空间域，重建残差信号。
- **Adder (+)**: Adds the reconstructed residual error to the predicted frame to form the reconstructed frame.**加法器(+)**：将重构残差与预测帧相加，形成重构帧。
- **Reconstructed Frame**: Used as a reference for encoding subsequent frames.
  重建帧：用作编码后续帧的参考。

The feedback loop from the **Reconstructed Frame** back to the **Motion Estimation (ME)** ensures that both the encoder and decoder use the same reference frames, maintaining synchronization and reducing errors in motion prediction.

从**重构帧**返回到**运动估计 (ME) 的**反馈回路可确保编码器和解码器使用相同的参考帧，从而保持同步并减少运动预测中的错误。

(i) Reason for Using Slice Structure:(i) 使用切片结构的原因：

The slice structure divides a video frame into smaller, independently decodable units called slices, each consisting of a series of macroblocks. This structure is used for:

切片结构将视频帧划分为更小的、可独立解码的单元（称为切片），每个单元由一系列宏块组成。该结构用于：

- **Error Resilience**: By containing errors within a slice, the impact of data corruption is limited, preventing it from affecting the entire frame.

  错误恢复能力：通过将错误包含在切片内，可以限制数据损坏的影响，从而防止其影响整个帧。

- **Parallel Processing**: Slices can be processed independently, allowing for simultaneous encoding and decoding, which enhances processing efficiency.

  并行处理：切片可以独立处理，允许同时编码和解码，从而提高处理效率。

- **Memory Management**: Handling smaller units reduces memory requirements, facilitating processing in systems with limited resources.

  内存管理：处理较小的单元可以减少内存需求，从而促进资源有限的系统中的处理。

(ii) Advantage and Disadvantage of Multiple Slices per Frame:

(ii) 每帧多个切片的优点和缺点：

- **Advantage:优势**：

  - **Improved Error Resilience**: Multiple slices ensure that if one slice is corrupted during transmission, the rest of the frame can still be decoded correctly, enhancing overall robustness.

    改进的错误恢复能力：多个切片确保如果一个切片在传输过程中损坏，帧的其余部分仍然可以正确解码，从而增强整体鲁棒性。

- **Disadvantage:缺点**：

  - **Reduced Coding Efficiency**: Using multiple slices can hinder the exploitation of spatial redundancies across slice boundaries, as predictions are typically confined within a slice, leading to less efficient compression.

    编码效率降低：使用多个切片可能会阻碍跨切片边界的空间冗余的利用，因为预测通常局限于一个切片内，从而导致压缩效率较低。

(c) Description of I-frame, P-frame, and B-frame in a GOP:

(c) GOP中I帧、P帧、B帧的说明:

- **I-frame (Intra-coded Frame):I 帧（帧内编码帧）**：
    - Encoded without reference to other frames.不参考其他帧进行编码。
    - Uses only spatial compression techniques like DCT and quantization.

      仅使用 DCT 和量化等空间压缩技术。
    - Serves as a reference point for decoding subsequent frames and allows random access points in the video stream.

      用作解码后续帧的参考点，并允许视频流中的随机访问点。
- **P-frame (Predictive-coded Frame):P 帧（预测编码帧）**：
    - Encoded using motion-compensated prediction from the previous I-frame or P-frame.使用来自先前 I 帧或 P 帧的运动补偿预测进行编码。
    - Exploits temporal redundancies by referencing past frames.

      通过引用过去的帧来利用时间冗余。
    - More efficient than I-frames due to temporal compression.

      由于时间压缩，比 I 帧更有效。
- **B-frame (Bi-directionally Predictive-coded Frame):B 帧（双向预测编码帧）**：
    - Encoded using motion-compensated prediction from both previous and future I-frames or P-frames.使用来自先前和未来 I 帧或 P 帧的运动补偿预测进行编码。
    - Offers the highest compression efficiency by utilizing both past and future frame data.通过利用过去和未来的帧数据提供最高的压缩效率。
    - Cannot be used as reference frames for other B-frames but can be for P-frames.

      不能用作其他 B 帧的参考帧，但可以用作 P 帧的参考帧。

(d) Analysis of the Given Codewords:

Symbol (S)	Codeword
a	1100
b	1001
c	101
d	111
e	10
f	0

To determine if these codewords can be Huffman codewords, we assess whether the code is **prefix-free** and satisfies the **Kraft-McMillan inequality**.

为了确定这些码字是否可以是霍夫曼码字，我们评估代码是否**无前缀**并满足**Kraft-McMillan 不等式**。

- **Prefix-Free Check:无前缀检查**:
  - The codeword for **e (10)** is a prefix of the codeword for **c (101)**.

    e (10)的码字是**c (101)**的码字的前缀。
  - Since **10** is the beginning of **101**, the code is not prefix-free.

    由于**10**是**101**的开头，因此该代码不是无前缀的。
  - In Huffman coding, all codewords must be prefix-free to ensure unique decodability.

    在霍夫曼编码中，所有码字必须是无前缀的，以确保唯一的可解码性。
- **Kraft-McMillan Inequality:卡夫-麦克米伦不等式**:
  - Calculate the sum $\sum 2^{-l_i}$, where l_i is the length of each codeword.

    计算总和 $\sum 2^{-l_i}$ ， 在哪里 l_i 是每个码字的长度。
  - Codeword lengths:码字长度:
    - $l_a = 4, l_b = 4, l_c = 3, l_d = 3, l_e = 2, l_f = 1.$
  - Sum:和:

    $$2^{-4} + 2^{-4} + 2^{-3} + 2^{-3} + 2^{-2} + 2^{-1} = \frac{1}{16} + \frac{1}{16} + \frac{1}{8} + \frac{1}{8} + \frac{1}{4} + \frac{1}{2} = \frac{9}{8} > 1$$
  - The sum exceeds 1, violating the Kraft-McMillan inequality.

    总和超过 1，违反了 Kraft-McMillan 不等式。

Conclusion:结论:

- **The codewords cannot be Huffman codewords** because:**码字不能是霍夫曼码字，**因为:
  - The code is not prefix-free, which is essential for Huffman coding to ensure unique decodability.该代码不是无前缀的，这对于霍夫曼编码确保唯一的可解码性至关重要。
  - The sum of 2^{-l_i} exceeds 1, violating the Kraft-McMillan inequality, indicating that a uniquely decodable code cannot be constructed with these codeword lengths.

    总和 2^{-l_i} 超过 1，违反了 Kraft-McMillan 不等式，表明无法使用这些码字长度构造唯一可解码的代码。