JPEG Compression

- Images consist of samples of values
- Consume tremendous space
- Compression schemes: encode images to consume less space

JPEG: Joint Photographic Experts Group Compression Standards

- Sequential encoding: (focus on this)
  - Each image component encoded in one left-to-right, top-to-bottom scan
- Progressive encoding:
  - Encoded in multiple scans;
  - Image builds from coarse to clear
- Lossless encoding:
  - Guarantee exact recovery of every source image sample value
- Hierarchical encoding:
  - Image encoded at multiple resolutions;
  - Access lower resolution without having to decode full resolution

Encoding

- **For simplicity, first look at gray-scale images**
- **Source image data = 8 x 8 blocks of samples**
- **Steps:**
  - **Forward Discrete Cosine Transfer (DCT)**
    - » **Lossless**
  - **Quantizer: uses tables**
    - » **Losses occur on this step**
  - **Entropy Encoder: uses tables**
    - » **Huffman Coding or Arithmetic Coding**
    - » **Lossless**

Decoding

- **Reverse process**
- **Steps:**
  - **Entropy decoding: uses tables**
  - **Dequantizing: uses tables**
  - **Inverse Discrete Cosine Transfer**
    - » **Reconstructs data image**

Forward Discrete Cosine Transfer

- **Input samples: converted to signed integers**
- **Input to FDCT**
- **Intuition:**
  - **8 x 8 block of samples = 64-point discrete signal**
  - **FDCT decomposes them into 64 orthogonal basis signals**
  - **Each contains a 2-dimensional "spatial frequency" (one of 64)**
- **Lossless**
- **IDCT: inverse function used in decode phase**
- **JPEG doesn't specify FDCT or IDCT algorithm**

DCT Coefficients

- **DCT coefficients: basis-signal amplitudes**
- **Relative amounts of each 2-d spatial frequency in 64-point input signal**
- **One DC coefficient (zero frequency in both dir.)**
- **63 AC coefficients:**
  - **Most of signal in lower spatial frequencies**
  - **Most frequencies have ero or near-zero frequencies**
  - **Those need not be encoded**

Quantization

- Rounding step: where losses occur
- Use 64-element quantiation table
  - Input to encoder
  - Elements are integers 1 to 255
  - Specify step size (weighting factor) for corresponding DCT coefficient
- Idea: represent each coefficient with minimum precision for desired quality
- Quantization:
  - Divide each DCT coefficient by corresonding step size
  - Then round to nearest integer
  - Normalize by step size

Quantization (Continued)

- Dequantization: Multiply by step size
- If want to compress as much as possible without visual artifacts:
  - Choose each step size at perception threshold

DC Coding and Zig-Zag Sequence

- **After quantization: DC Coefficient treated differently**
- **Measure of average value of 64-image samples**
- **Strong correlation between adjacent DC block terms**
- **Encode as differentials**
- **Then encode all signals in zig-zag order**
- **Place low-frequency coefficients first**
  - **Much more likely to be non-zero**

Entropy

- **Additional Compression phase**
- **Lossless**
- **Encode quantized DCT coefficients compactly based on statistical characteristics**
- **Two entropy coding schemes:**
  - **Huffman coding**
    - » **Requires tables**
      - **Either as input or inferred from initial pass over data**
  - **Arithmetic coding**
    - » **Requires no tables**
    - » **More complex to implement**

Entropy (Continued)

- **Two steps:**
  - **– Convert zig-zag sequence to intermediate sequence of symbols**
  - **– Convert symbols to compressed data stream**
    - **» No eternally identifiable boundaries**

Entropy Example: Baseline Sequential (Uses Huffman Coding)

- **Minimum JPEG functionality**
- **Conversion to Intermediate Symbols:**
  - **– Each of 63 nonzero AC coefficients:**
    - **» symbol 1 (runlength, size)**
    - **» symbol 2 (amplitude)**
      - **runlegth = number of zero coefficients preceding the current nonzero coefficient**
      - **size = number bits for current amplitude**
    - **» Longer sequence of zero: special case**
  - **– Differential DC coefficient:**
    - **» symbol 1 (size)**
    - **» symbol 2 (amplitude)**

Entropy Example: Baseline Sequential (Uses Huffman Coding)

- **Variable-Length Entropy Encoding**
  - **Each 8 x 8 block**
    - » **First code DC coefficient**
    - » **Then AC coefficients**
  - **Symbol 1: Use VLC**
    - » **Variable length codes**
    - » **From Huffman tables**
  - **Symbol 2: use VLI**
    - » **Variable length integer codes**
    - » **Size depends on amplitude**

DCT-Based Modes: Different Picture Quality

- **0.25 to 0.5 bits/pixel: moderate to good**
- **0.5 to 0.75 bits/pixel: good to very good**
- **0.75 to 1.5 bits/pixel: excellent**
- **1.5 to 2.0 bits/pixel: indistinguishable from original**

Lossless Mode

- Does not use DCT
- Placed constraints on implementation
- Simple predictive method
- Combine values of up to 3 neighbors into prediction
  - Subtract from actual value
  - Encode difference losslessly with one of entropy coding methods
- Lossless compression approximately 2 to 1

Multiple Component Images

- Color or other images have multiple components
- Component = array of samples
- 1 to 255 components per image
- Also called spectral bands or channels
- All samples in a component have same precision P
- P = bits used to encode a sample
  - DCT-based codecs: P = 8 or 12 bits
  - Predictve codecs: P = 2 to 16 bits
- Different components of an image can have different dimensions (sampled at different rates)
- Component i has dimensions Xi by Yi

Multiple Component Images (Cont)

- Dimensions have integral relationship
- Hi, Vi are relative horizontal, vertical sampling factors
- Data unit
  - Predictive codec: one sample
  - DCT: 8 x 8 block of samples
- Order of compressed units in data stream:
  - Generally: left to right, top to bottom

Interleaving

- Image components may be interleaved
- Necessary where display of image requires simultaneously decoding multiple components
- Components Ci partitioned into rectangular regions
- Regions within component ordered
  - left to right, top to bottom
- Data units within a region
  - left to right, top to bottom
- Minimum Coded Unit (MCU)
  - Smallest group of data interleaved units
- Maximum interleaved components = 4
- Maximum data units per MCU = 10

Tables

- **Store up to four quantization tables**
  - **1 for each interleaved component**
- **Swtich between tables during entropy encoding**

Progressive Mode

- **Same FDCT, Quantization Steps**
- **Diference: encode images in multiple scans**
- **First: rough, recognizable**
  - **Can be transmitted quickly compared to total transmission time**
- **Successive scans: refine until reach picture quality estimaed by quantization tables**
- **Implementation:**
  - **Need image-sized buffer after quantizer**
  - **Partially encode in each of multiple scans**

Progressive Mode (Continued)

- Options:
- Quantized DCT coefficients viewed as rectangle
  - 64 DCT coefficients and amplitudes
- (1) Only specified bands
- (2) Coefficients in each band not encoded at full accuracy

Hierarchical Mode

- Pyramid: multiple resolutions
- Each different by a factor of 2 in horizontal, vertical, or both
- Procedure:
- Filter down to lowest resolution; encode (lossy or lossless)
- Repeate these steps
  - Decode that image; upsample by interpolation
  - Use sampled image as prediction of original
  - Encode difference (seq. or prog. DCT or lossless)
- until encode to full resolution