Administrative

- MP1 deadline today, February 18
- Help session, Today, February 9, 7-9pm, room:1111 SC
Outline

- JPEG-2000 Compression

  **Reading:** Section 7.5 in Media Coding book, Steinmetz & Nahrstedt, and http://en.wikipedia.org/wiki/JPEG_2000 and links in slides
JPEG Steps Review

- **Image Preparation**
  - Components Separation
  - Block Division (8x8 Blocks) of each Component

- **Image Processing**
  - Pixel Value Shifting
  - 2D DCT Transformation
  - Creation of DC and AC Coefficients

- **Quantization**
  - Quantization Tables

- **Entropy Coding**
  - Zig-Zag Ordering
  - DC Coefficients – Differential Coding
  - AC Coding - RLE & Huffman Coding
JPEG-2000

Original (uncompressed TIF 116KB)

JPEG (8:1, 14KB)

JPEG-2000 (8:1, 14KB)

http://www.photographical.net/jpeg2000.html

CS 414 - Spring 2011
JPEG-2000

- Created in 2000 by JPEG committee
- File extension:
  - `jp2` for ISO/IEC 15444-1 conforming files
  - `image/jp2` for MIME type
JPEG-2000 Features

- **Low bit rate compression performance**
  - Current standards offer excellent rate-distortion performance in mid and high bit rates
  - Low bit rate distortions become unacceptable

- **Lossless and lossy compression**
  - Current standard does not provide superior lossless and lossy compression in a single code-stream
JPEG-2000 Features

- Large Images
  - Current standard does not allow for images larger than 64Kx64K pixels without quality degradation

- Single decompression architecture
  - Current standard has 44 modes (application specific, and not used by majority JPEG coders)
  - Single common decompression architecture can provide greater interchange between applications
JPEG-2000 Features

- Transmission in noisy environment
  - Current standard has provision for restart intervals, but image degrades badly when bit errors occur.

- Computer generated imagery (Graphics)
  - Current standard is optimized only for natural imagery

- Compound documents
  - Current standard is not applied to compound documents because of its poor performance when applied to text imagery
JPEG-2000 Features

- Superior **low bit rate performance**
  - Below 0.25 bits per pixel for highly detailed grey-scale images

JPEG-2000 Features

- Lossless and lossy compression
  - Lossless compression uses progressive decoding (i.e., difference image encoding) for medical imaging

- Progressive transmission by pixel accuracy and resolution
  - Reconstruction of images is possible with different resolutions and pixel accuracy for different target devices
JPEG-2000 Features

- Random code-stream access and processing
  - Needed in case images have parts that are more important than others
  - User defines “regions-of-interest” in the image to be randomly accessed and/or decompressed with less distortion than the rest of images
  - random code-stream processing allows operations: rotation, translation, filtering, feature extraction, scaling,…
Methods of Compression

- **DCT-based coder**
  - New baseline JPEG algorithm required for backward compatibility with existing JPEG

- **Wavelet-based coder**
  - This method permits coding of still images with high coding efficiency as well as spatial and SNR (signal-to-noise ratio) scalability at fine granularity (see also tutorial – part1/part2/part3 - http://users.rowan.edu/~polikar/WAVELETS/WTpart1.html)
Color Component Transformation

- JPEG-2000: transformation from RGB to $Y_{C_B}C_R$ or YUV
  - Irreversible Color Transform:
    - uses the well known $Y_{C_B}C_R$ color space. It is called "irreversible" because it has to be implemented in floating or fix-point and causes round-off errors.
  - Reversible Color Transform:
    - uses a modified YUV color space that does not introduce quantization errors, so it is fully reversible.
Wavelet Transform

- DWT (Discrete Wavelet Transform) extracts information from the source image at different scales, locations and orientations

- JPEG-2000 uses 2D wavelets and multi-scale transforms

- Wavelet is defined as a set of basic functions, derived from the same prototype function

- Prototype function is known as “mother wavelet”
  - Examples: “Mexican Hat” wavelet, Haar wavelet
Continuous Wavelet Transform

In one dimension,

\[ f(x) \in L_2(R), \quad cwt(s, b) = \frac{1}{\sqrt{s}} \int f(x)\psi \left( \frac{x-b}{s} \right) dx \]  \hspace{2cm} \text{(time domain)}

\[ CWT(s, w) = \sqrt{s} F(w) \Phi(sw) \] \hspace{2cm} \text{(frequency domain)}

\( s \) – scale parameter, \( b \) – location parameter, \( \psi(x) \) – analyzing wavelet, \( cwt \) – wavelet coefficient

In two dimension,

\[ f(x, y) \in L_2(R), \quad cwt(s, a, b) = \frac{1}{\sqrt{s}} \iint f(x, y)\psi \left( \frac{x-a}{s}, \frac{y-b}{s} \right) dx dy \]  \hspace{2cm} \text{(time domain)}

\[ CWT(s, w1, w2) = \sqrt{s} F(w1, w2) \Phi(sw1, sw2) \] \hspace{2cm} \text{(frequency domain)}

We want to calculate 2D CWT in frequency domain

When scale \( s \) is fixed,

\[ CWT(w1, w2) = F(w1, w2) \Phi(w1, w2) \]
1D/2D Mexican Hat ‘analyzing wavelet’

Time domain

$$\Psi(x, y) = (x^2 + y^2 - 2)e^{-\frac{1}{2}(x^2+y^2)}$$

$$\psi(x) = (1 - \frac{x^2}{\sigma^2})e^{-\frac{x^2}{2\sigma^2}}$$
2D Mexican Hat ‘analyzing wavelet’

Time domain

\[ \Psi'(x, y) = (x^2 + y^2 - 2)e^{-\frac{1}{2}(x^2+y^2)} \]

Frequency domain

\[ \Phi(w_1, w_2) = -2\pi(w_1^2 + w_2^2)e^{-\frac{1}{2}(w_1^2+w_2^2)} \]
Example of artifacts produced by wavelet transform (for different scale parameters)
Wavelet Transform Properties

- Wavelet transform coders process high and low frequency parts of image independently
  - DCT methods have difficulties with high-frequency information
- Wavelet method transforms image as a whole (not subdivided into pixel blocks)
  - No blocking artifacts occur
  - Wavelet coders degrade gracefully
Forward Wavelet Transform

- Image is first filtered along the x dimension, resulting in low-pass and high-pass image.
- Since bandwidth of both low pass and high pass image is now half that of the original image, both filtered images can be down-sampled by factor 2 without loss of information.
- Then both filtered images are again filtered and down-sampled along the y dimension resulting in four sub-images.
Wavelet Transform
Wavelet Transform (1)
Wavelet Transform (2)
JPEG-2000 Resolution Scalability

JPEG-2000 Scalability

- Scalable in both SNR and resolution

Example of resolution progressive bit-stream ordering
JPEG-2000 Scalability

✓ With JPEG 2000 several levels of resolution or detail are coded in the compressed image file.
✓ When accessing a JPEG 2000 image across a network, a low resolution image (or a full resolution image with low detail) can be extracted from the compressed image stored on the server (1)
✓ If more quality is desired, more information can be extracted from the compressed file on the server to increase the resolution or detail locally (2)
✓ There is no data redundancy in the compressed image and therefore for this type of application JPEG 2000 is very efficient
JPEG-2000 Scalability

- JPEG 2000 also supports selective extraction of image data from a particular region.
- Use of this feature allows areas of interest to be viewed at higher quality while minimizing the amount of data needed to be transferred over the network.
- This is particularly useful when viewing images on limited bandwidth networks and when using low power devices with limited display capabilities - such as mobile devices.
JPEG-2000 Performance

- Gain up to about 20% compression performance to the first JPEG standard
- Applications of JPEG-2000
  - Large images
  - Images with low-contrast edges (e.g., medical images)
  - In printers, scanners, facsimile
  - HD satellite images
Applications of Motion
JPEG2000

- Leading digital film standard
- Supported by Digital Cinema Initiatives for storage, distribution and exhibition of motion pictures
- Considered by Library of Congress to be the digital archival format
Conclusion - Artifacts of JPEG-2000 Compression

• Compression 1/20 size is without incurring visible artifacts
• If artifacts occur, they can be seen as smoothing rather than squares or mosquito noise
Available Software Implementation

- JJ2000: Java (Canon/Ericsson/EPFL)  
  - free reference software
- Jasper: “C” (Adams/Imagepower/UBC)  
  - free reference software
- Kakadu: “C++” (Taubman/UNSW)  
  - probably most popular commercial system
- Luratech/AlgoVision
- Aware Inc.
- Ricoh (TRUEW)
- Imagepower
Available Hardware Implementation

- **Analog Devices**
  - ADV-JP2000 was first to implement (partially)

- **Amphion**
  - IP Core claims 60 Msamples/second
  - May do only the wavelet transform part

- **Picture Elements Inc.**
  - Nearing release of high-performance compressor for scanners

- **Ricoh, Imagepower, ...**
  - Working on chips; status unknown