Review of Last Class

- Discussions on free-lunch issues of data hiding
- Fine granularity scalable coding
  - Drift
  - Bit-plane coding

Today
- FGS performance and discussions
- Wavelet coding for achieving scalability

FGS Tool: Bit-plane Coding (clarifications)

- Bit-plane coding for successive approximation
  - Binary representation: $i$-th bit determines whether to add $L/2^i$

- Optimal reconstruction value with an $i$-bit representation
  - Recall MMSE quantizer

$$
\begin{array}{c}
1 \times L/2 \\
0 \times L/4 \\
1 \times L/8 \\
1 \times L/16
\end{array}
$$
**Example: Bit-Plane Coding**

- Bit-plane coding into (Run, EOP) symbol
  - Run ~ # of zeros before a “1”
  - EOP flag ~ end-of-plane
  - Encode sign right after the VLC code of (Run, EOP) symbol containing MSB of the associated non-zero coeff. value

Example:

```
20,6,0,9,3,0,2,0,0,0,1,0,...,0 (absolute)
0,1,1,1,1,1,1,0,0,0,1,1,0,0,0,1,0,0,0,1,0 (sign bits)
```

Therefore, the 4 bit-planes are considered in forming the (RUN, EOP) symbol. Writing every value in the binary format, the 4 bit-planes are formed as follows:

- Run: 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 (MSB)
- Run: 0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0 (MSB-1)
- Run: 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0 (MSB-2)
- Run: 0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1,0 (MSB-3)

Converting the four bit-planes into (RUN, EOP) symbols, we have:

- (0,1) (MSB)
- (0,1) (MSB-1)
- (0,1) (MSB-2)
- (0,1) (MSB-3)

**Run-level vs. Bit-Plane Coding**

- [(Run, Level), value] coding
  - Used in traditional DCT coding (following quantiz. and zig-zag scan)
  - “run” # of zeros before nonzero coeff., “level” (range of coeff. mag.)
  - (Run, Level) statistics depends on quantization step size
    - Large Q lead to more symbols of long run and small level
    - Hard to design one VLC table suits all Q

- Bit-plane coding
  - (Run, EOP) statistics are quite independent of quantization step size
  - Use different VLC table for different bit-planes
  - More efficient than run-level coding
    - Up to 20% coding gain esp. for small quantization step size

**Coding Gain of Bit-plane Coding over Run-level**

Diagram is from W.Li's CSVT 3:01 paper Fig.6(a)

**FGS's Performance via Bit-plane Coding of DCT**

- Adopted by Streaming Video Profile (in MPEG-4 Amendment)
  - Encode base layer using non-scalable coding
  - Enhancement layer encodes difference between original & reconstructed picture
    - Uses bit-plane coding on DCT coeff. of the difference

- FGS vs. multi-layer SNR scalability
  - FGS is about 2dB better due to coding gain of bitplane over run-level

- FGS vs. best non-scalable coding
  - FGS is about 2dB worse (nonscalable serves as performance bound of FGS)
  - Ref. for motion prediction is base-layer rather than the high-quality picture

- FGS vs. simulcast (several non-scalable streams at different rate)
  - FGS (smooth quality changes) vs. simulcast (abrupt step change)

Results: W.Li’s Sec.V Fig.19-21
Discussions on F.G.S.

- If always using base-layer as motion prediction reference for all enhancement layers
  - Less error propagation, easier error recovery (just need correct base layer)
  - Residue would be larger than using reconstruction from high quality layers as reference so coding efficiency is reduced

- Solutions to coding efficiency problem ~ Progressive F.G.S.
  - With careful assignment of reference layers for prediction
    - Periodically use intermediate enhancement layers as MC reference
      [Ref.] Feng Wu et al. Trans. CSVT 3/2001 pp332-344

- Wavelet coding: An alternative way to DCT-bitplane F.G.S.
  - Inherent multiresolution structure
  - Bit-plane coding such as in Embedded Zero Tree (EZW)
Scalability via Wavelet-based Coding

Wavelet Transform for Image Compression

- **Today’s emphasis**
  - Conceptual aspects related to image compression
  - Wavelet is also useful for denoising, enhancement, and image analysis
  - For more info. on wavelet: ENEE624, wavelet math course, & other ref.

- **K-level 1-D wavelet decomposition**
  - Successive lowpass/highpass filtering and downsampling
    - on different level: capture transitions of different frequency bands
    - on the same level: capture transitions at different locations

Examples of 1-D Wavelet Transform

Multi-resolution Analysis by 2-D Wavelet Transf.

- Easy to achieve scalability: spatial-frequency, SNR
Subband Coding Techniques

- General coding approach
  - Allocate different bits for coeff. in different frequency bands
  - Encode different bands separately
  - Example: DCT-based JPEG and early wavelet coding

- Minor difference between subband coding and early wavelet coding
  - Choices of filters
    - Subband filters aim at (approx.) non-overlapping freq. response
    - Wavelet filters typically designed for certain smoothness constraints

- Shortcomings of subband coding
  - Difficult to determine optimal bit allocation for low bit rate applications
  - Not easy to accommodate different bit rates with a single code stream
  - Difficult to encode at an exact target rate

Embedded Zero-Tree Wavelet Coding (EZW)

- “Modern” lossy wavelet coding exploits multi-resolution and self-similar nature of wavelet decomposition
  - Energy is compacted into a small number of coeff.
  - Significant coeff. tend to cluster at the same spatial location in each freq. subband

Two Key Concepts of EZW

- Significance map coding via zero-Tree
  - If encode only high-energy coefficients
    - Need to send location info. ➔ large overhead
  - Encode “insignificance map” using zero-trees
    - Symbols of zero-tree root and isolated zeros

- Successive approximation on signif. coefficients
  - Similar to bit-plane coding discussed earlier
  - Send most-significant-bits first and gradually refine coeff. value
  - “Embedded” nature of coded bit-stream
    - get higher fidelity image by adding extra refining bits ➔ fine granular scalability

- Also, DC band is differentially coded

Wavelet-based Video Coding

- Three main categories
  - Spatial domain motion compensation ➔ 2-D DWT on MC residue
  - 2-D DWT ➔ freq.-domain motion compensation
  - 3-D DWT and coding (with and without motion compensation)

- Wavelet video coding vs. widely used DCT-hybrid coding
  - Insignificant benefits of Wavelet approach for videos except scalability

- Claimed 3dB gain of Wavelet coding over DCT for images
  - Comparison w.r.t JPEG Baseline: DCT coder can be further improved
  - Wavelet advantage is not all due to transforms
    - Main contribution from better rate allocation, advanced entropy coding, & smarter redundancy reduction via zero-tree

Summary

- Fine granularity scalable coding (cont’d)
  - Performance
  - Discussions

- Wavelet coding for achieving scalability
  - Multi-resolution nature of wavelet transform
  - FGS through coeff. tree structure and bit-plane coding

- Next Time:
  - Other coding problems related to layered coding

Suggested Reading

- Related tech. publications on F.G.S.
  - Tutorials/surveys in IEEE CSVT 3/01 special issue on streaming video
    - W.Li’s survey on MPEG-4 FGS (DCT bitplane)
    - F.Wu et al.’s progressive FGS

- Wavelet-based image coding
  - Sec.11.3 of Wang’s video textbook
  - Usevitch’s tutorial in IEEE Sig. Proc. Magazine 9/01

Questions for Today

- Transmit an image (say, Lena) using two channels
  - Data sent over each channel may get lost
  - Conditions of two channels are independent
    - Prob. that both channels are bad at the same time is very small

  [ Codec Design Goal ]
  - Fix the total # of bits to be sent over the two channels
  - When only one channel is good, want to get image decoded with reasonable perceptual quality
  - When both ch. are good, want to get image decoded with improved quality

  [Bonus] design and implement a proof-of-concept test of the best approach you can think of