CS 414 – Multimedia Systems Design

Lecture 5 – Basics of Compression (Part 1)

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Administrative

- MP1 is posted
- Discussion meeting on Thursday, January 31, at 7pm, 3403 SC.

Need for Compression

- Uncompressed audio
- 8 KHz, 8 bit
  - 8K per second
  - 30M per hour
- 44.1 KHz, 16 bit
  - 88.2K per second
  - 317.5M per hour
- 100 Gbyte disk holds 315 hours of CD quality music

- Uncompressed video
- 640 x 480 resolution, 8 bit color, 24 fps
  - 7.37 Mbytes per second
  - 26.5 Gbytes per hour
- 640 x 480 resolution, 24 bit (3 bytes) color, 30 fps
  - 27.6 Mbytes per second
  - 99.5 Gbytes per hour
- 100 Gbyte disk holds 1 hour of high quality video

Broad Classification

- Entropy Coding (statistical)
  - lossless; independent of data characteristics
  - e.g. RLE, Huffman, LZW, Arithmetic coding
- Source Coding
  - lossy; may consider semantics of the data
  - depends on characteristics of the data
  - e.g. DCT, DPCM, ADPCM, color model transform
- Hybrid Coding (used by most mm systems)
  - combine entropy with source encoding
  - e.g., JPEG, H.263, MPEG-1, MPEG-2, MPEG-4

Overview

- Compression refers to a process; *coding*
  - coding refers to a process of representing data such that it satisfies a particular need

- Information theory studies efficient coding algorithms
  - complexity, compression, likelihood of error

Data Compression

- Branch of information theory
  - minimize amount of information to be transmitted
- Transform a sequence of characters into a new string of bits
  - same information content
  - length as short as possible

Concepts

- Coding (the code) maps source messages from alphabet (*A*) into code words (*B*)

- Source message (symbol) is basic unit into which a string is partitioned
  - can be a single letter or a string of letters

- EXAMPLE: aa bbb cccc ddddd eeeeee fffffffgggggggg
  - *A* = {a, b, c, d, e, f, g, space}
  - *B* = {0, 1}

Taxonomy of Codes

- Block-block
  - source msgs and code words of fixed length; e.g., ASCII
- Block-variable
  - source message fixed, code words variable; e.g., Huffman coding
- Variable-block
  - source variable, code word fixed; e.g., RLE, LZW
- Variable-variable
  - source variable, code words variable; e.g., Arithmetic

Example of Block-Block

- Coding “aa bbb cccc ddddd eeeeee fffffffgggggggg”

- Requires 120 bits

Symbol	Code word
a	000
b	001
c	010
d	011
e	100
f	101
g	110
space	111

Example of Variable-Variable

- Coding “aa bbb cccc ddddd eeeeee fffffffgggggggg”
- Requires 30 bits
  - don’t forget the spaces

Symbol	Code word
aa	0
bbb	1
cccc	10
ddddd	11
eeeeee	100
fffffff	101
gggggggg	110
space	111

Concepts (cont.)

- Source messages determined prior to coding
  - called the message *ensemble*

- A code is
  - *distinct* if each code word can be distinguished from every other (mapping is one-to-one)
  - *uniquely decodable* if every code word is identifiable when immersed in a sequence of code words
  - e.g., with previous table, message 11 could be defined as either ddddd or bbbbbb

Concepts (cont.)

- Uniquely decodable is a prefix free code
  - if no codeword is a proper prefix of any other
- For example {1, 100000, 00} is uniquely decodable, but is not a prefix code
  - consider the codeword {…1000000001…}
- Process of transforming a source ensemble into a coded message is called *coding* (encoding)

Static Codes

- Mapping is fixed before transmission
  - message represented by same codeword every time it appears in ensemble
  - Huffman coding is an example
- Better for independent sequences
  - probabilities must be known in advance; or values computed from other data sources

Dynamic Codes

- Mapping changes over time
  - also referred to as *adaptive* coding
- Attempts to exploit locality of reference
  - periodic, frequent occurrences of messages
  - dynamic Huffman is an example
- Hybrids?
  - build set of codes, select based on input

Traditional Evaluation Criteria

- Algorithm complexity
  - running time
- Amount of compression
  - redundancy
  - compression ratio
- How to measure?

Measure of Information

- Consider symbols s_i and the probability of occurrence of each symbol $p(s_i)$
- In case of **fixed-length coding** , smallest number of bits per symbol needed is
  - $L \geq log_2(N)$ bits per symbol
  - Example: Message with 5 symbols need 3 bits $(L \geq log_2 5)$

Variable-Length Coding-Entropy

- What is the minimum number of bits per symbol?
- Answer: Shannon's result – theoretical minimum average number of bits per code work is known as Entropy (H)

$$\sum_{i=1}^{n} -p(s_i)\log_2 p(s_i)$$

Entropy Example

- Alphabet = {A, B}
  - p(A) = 0.4; p(B) = 0.6
- Compute Entropy (H)
  - $-0.4*\log_2 0.4 + -0.6*\log_2 0.6 = .97$ bits
- Maximum uncertainty (gives largest H)
  - occurs when all probabilities are equal

Redundancy

- Difference between avg. codeword length (L) and avg. information content (H)
  - If H is constant, then can just use L
- Relative to the optimal value

Compression Ratio

- Compare the average message length and the average codeword length
  - e.g., average L(message) / average L(codeword)

- Example:
  - {aa, bbb, cccc, ddddd, eeeeee, fffffff, gggggggg}
  - average message length is 5

- Relative to the original data

Symmetry

- Symmetric compression
  - requires same time for encoding and decoding
  - used for live mode applications (teleconference)

- Asymmetric compression
  - performed once when enough time is available
  - decompression performed frequently, must be fast
  - used for retrieval mode applications (e.g., an interactive CD-ROM)

Entropy Coding Algorithms (Content Dependent Coding)

- Run-length Encoding (RLE)
  - Replaces sequence of the same consecutive bytes with number of occurrences
  - Number of occurrences is indicated by a special flag (e.g., !)
  - Example:
    - abcccccccccdeffffggg (20 Bytes)
    - abc!9def!4ggg (13 bytes)

Variations of RLE (Zero-suppression technique)

- Assumes that only one symbol appears often (blank)
- Replace blank sequence by M-byte and a byte with number of blanks in sequence
  - Example: M3, M4, M14,…
- Some other definitions are possible
  - Example:
    - M4 = 8 blanks, M5 = 16 blanks, M4M5=24 blanks

Huffman Encoding

- Statistical encoding
- To determine Huffman code, it is useful to construct a binary tree
- Leaves are characters to be encoded
- Nodes carry occurrence probabilities of the characters belonging to the subtree
- Example: How does a Huffman code look like for symbols with statistical symbol occurrence probabilities:

  $P(A) = 8/20$, $P(B) = 3/20$, $P(C) = 7/20$, $P(D) = 2/20$?

Huffman Encoding (Example)

Step 1 : Sort all Symbols according to their probabilities (left to right) from Smallest to largest

these are the leaves of the Huffman tree

P(B) = 0.51

P(C) = 0.09

P(E) = 0.11

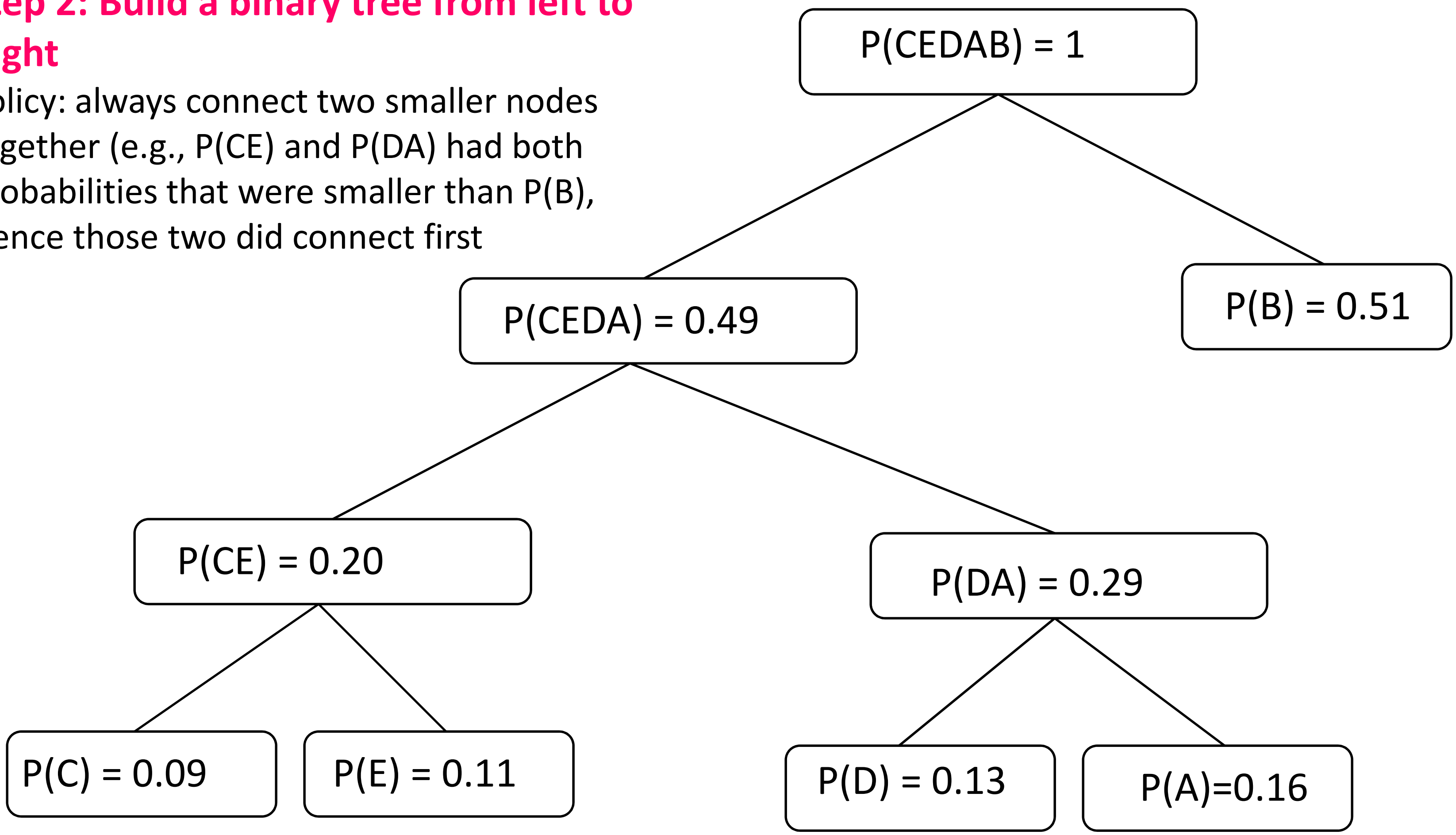
P(D) = 0.13

P(A)=0.16

Huffman Encoding (Example)

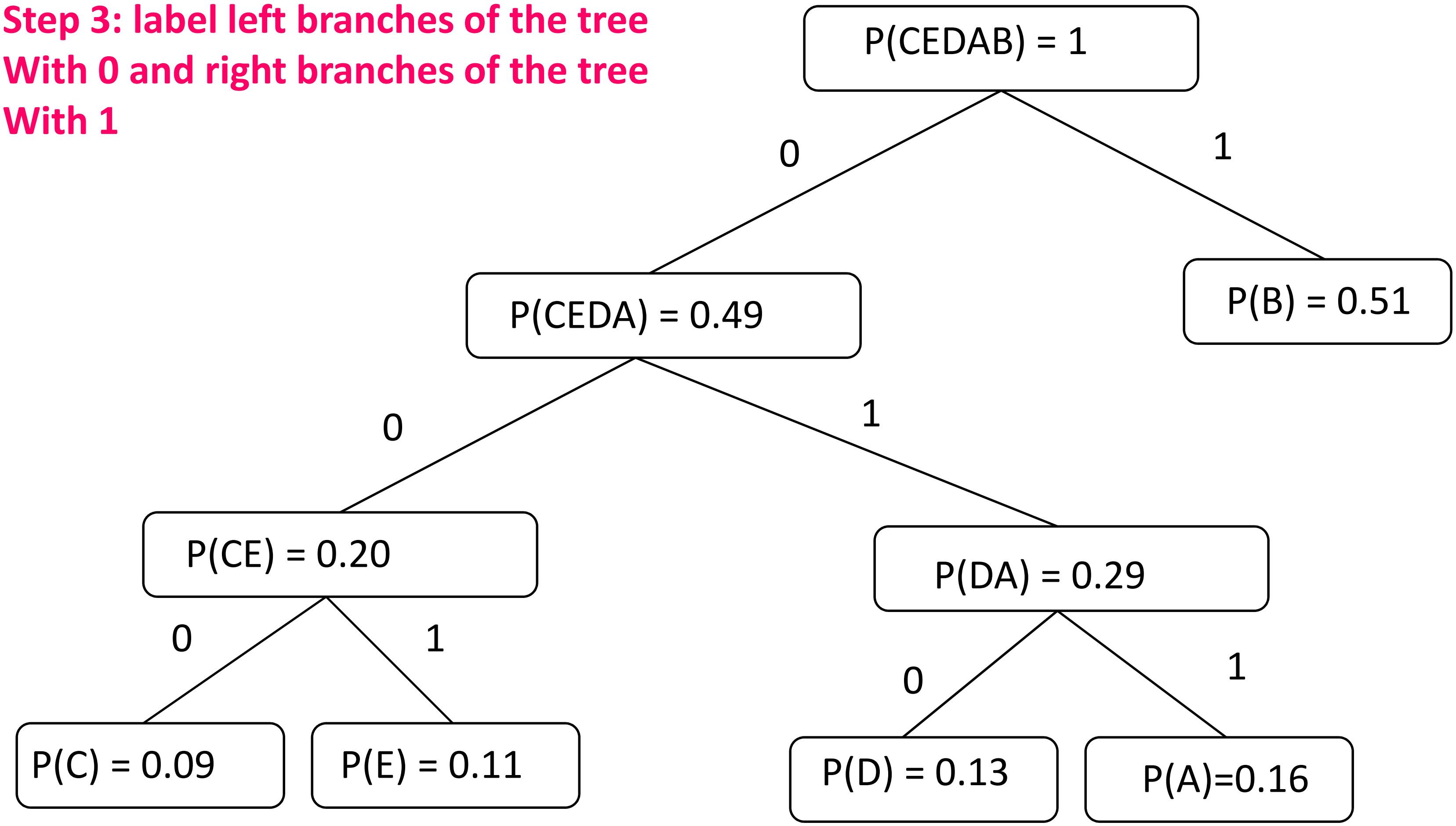
Step 2: Build a binary tree from left to Right

Policy: always connect two smaller nodes together (e.g., P(CE) and P(DA) had both Probabilities that were smaller than P(B), Hence those two did connect first



Huffman Encoding (Example)

Step 3: label left branches of the tree With 0 and right branches of the tree With 1



Huffman Encoding (Example)

Step 4: Create Huffman Code

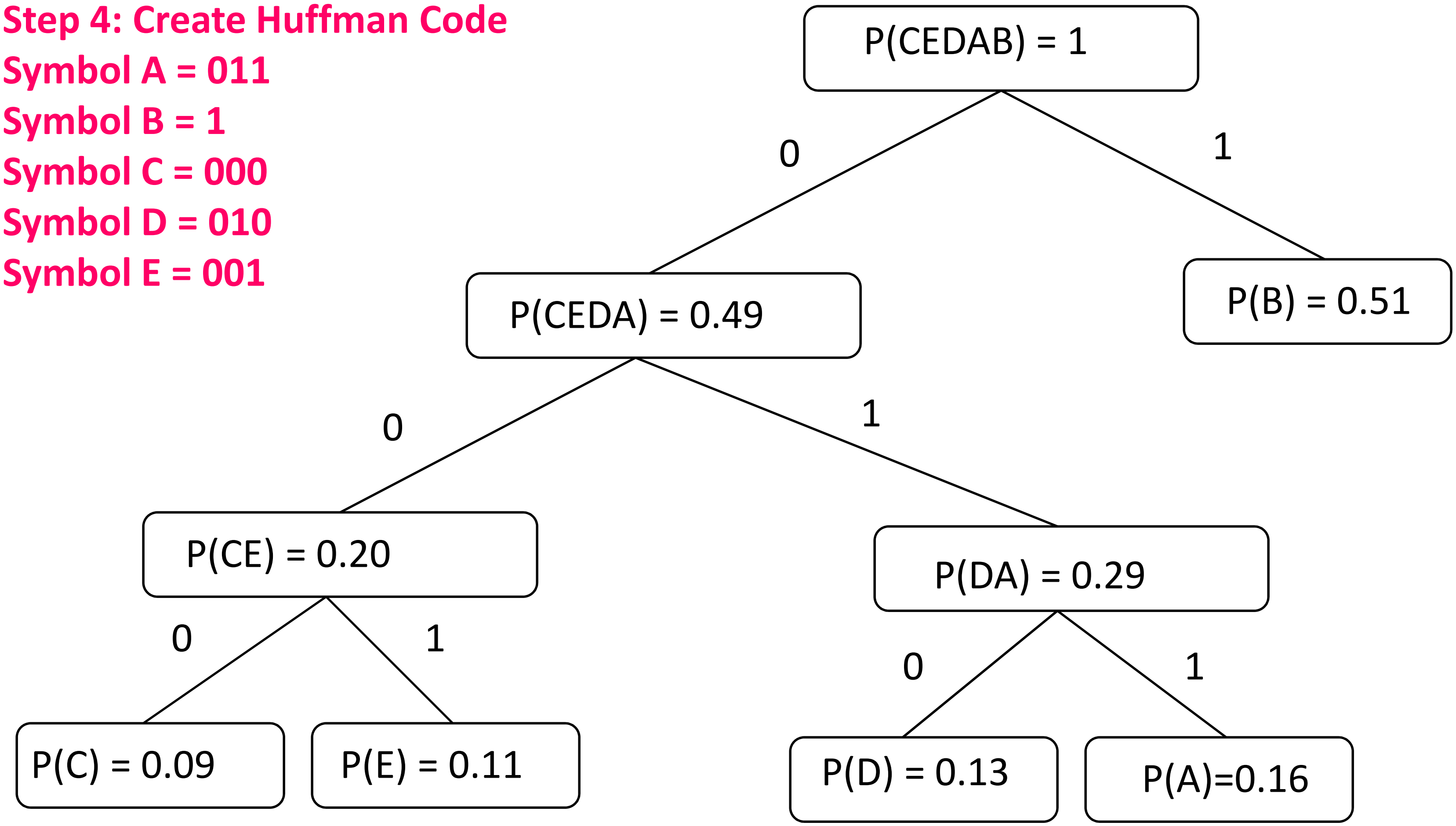
Symbol A = 011

Symbol B = 1

Symbol C = 000

Symbol D = 010

Symbol E = 001



Summary

- Compression algorithms are of great importance when processing and transmitting
  - Audio
  - Images
  - Video

Audio Compression and Formats

- MPEG-3
- ADPCM
- u-Law
- Real Audio
- Windows Media (.wma)

- Sun (.au)
- Apple (.aif)
- Microsoft (.wav)

Image Compression and Formats

- RLE
- Huffman
- LZW
- GIF
- JPEG
- Fractals

- TIFF, PICT, BMP, etc.

Video Compression and Formats

- H.261/H.263
- Cinepak (early 1992 Apple's video codec in Quick-time video suite)
- Sorensen (Sorenson Media, used in Quick-time and Macromedia flash)
- Indeo (early 1992 Intel video codec)
- Real Video (1997 RealNetworks)
- MPEG-1, MPEG-2, MPEG-4, etc.

- QuickTime, AVI, WMV (Windows Media Video)

Video compression	
ISO/IEC	MJPEG · MPEG-1 · MPEG-2 · MPEG-4 ASP · MPEG-4/AVC
ITU-T	H.120 · H.261 · H.262 · H.263 · H.264
Others	AMV · AVS · Bink · Dirac · Indeo · MJPEG · Pixlet · RealVideo · RTVideo · Smacker · Theora · VC-1 · VP6 · VP7 · WMV
Audio compression	
ISO/IEC	MPEG-1 Layer III (MP3) · MPEG-1 Layer II · MPEG-1 Layer I · AAC · HE-AAC · HE-AAC v2
ITU-T	G.711 · G.722 · G.722.1 · G.722.2 · G.723 · G.723.1 · G.726 · G.728 · G.729 · G.729.1 · G.729a
Others	AC3 · AMR · Apple Lossless · ATRAC · FLAC · iLBC · Monkey's Audio · μ-law · Musepack · Nellymoser · OptimFROG · RealAudio · RTAudio · SHN · Siren · Speex · Vorbis · WavPack · WMA · TAK
Image compression	
ISO/IEC/ITU-T	JPEG · JPEG 2000 · lossless JPEG · JBIG · JBIG2 · PNG · WBMP
Others	BMP · GIF · ICER · ILBM · PCX · PGF · TGA · TIFF · JPEG XR / HD Photo
Media containers	
General	3GP · **ASF** · AVI · Bink · DMF · DPX · FLV · Matroska · MP4 · MXF · NUT · Ogg · Ogg Media · QuickTime · RealMedia · Smacker · VOB