CMSC 132: OBJECT-ORIENTED PROGRAMMING II

Compression & Huffman Code

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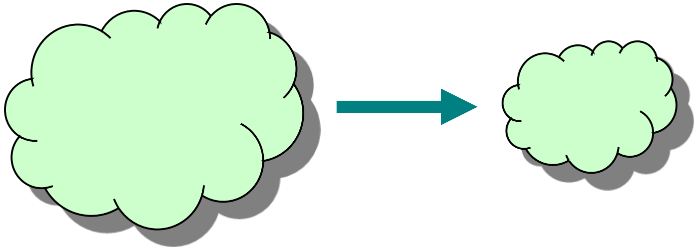
Overview

- **Compression**
  - Examples
  - Sources
  - Types
  - Effectiveness
- **Huffman Code**
  - Properties
  - Huffman tree (encoding)
  - Decoding

Compression

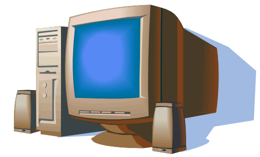
- **Definition**
  - Reduce size of data
    (number of bits needed to represent data)



- **Benefits**
  - Reduce storage needed
  - Reduce transmission cost / latency / bandwidth

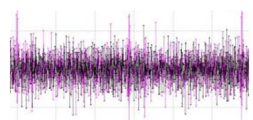
Compression Examples

- **Formats**
  - **General**
    - .zip, .rar



  - **Images**
    - .jpg, .gif

  - **Audio**
    - .mp3, .wmv



  - **Video**
    - .mpg, .mov

Sources of Compressibility

- **Redundancy**
  - Recognize repeating patterns
  - Exploit using
    - Dictionary
    - Variable length encoding
- **Human perception**
  - Less sensitive to some information
  - Can discard less important data

Types of Compression

- **Lossless**
  - Preserves all information
  - Exploits redundancy in data
  - Applied to general data
    - Some lossless audio formats (e.g., FLAC)
- **Lossy**
  - May lose some information
  - Exploits redundancy & human perception
  - Applied to audio, image, video, multimedia

Effectiveness of Compression

- Metrics
    - Bits per byte (8 bits)
        - 2 bits / byte $\Rightarrow$ ¼ original size
        - 8 bits / byte $\Rightarrow$ no compression
    - Percentage
        - 75% compression $\Rightarrow$ ¼ original size

Effectiveness of Compression

- Depends on data
  - Random data $\Rightarrow$ hard
    - Example: 1001110100 $\Rightarrow$?
  - Organized data $\Rightarrow$ easy
    - Example: 1111111111 $\Rightarrow$ 1×10
- Corollary
  - No universally best compression algorithm

Effectiveness of Compression

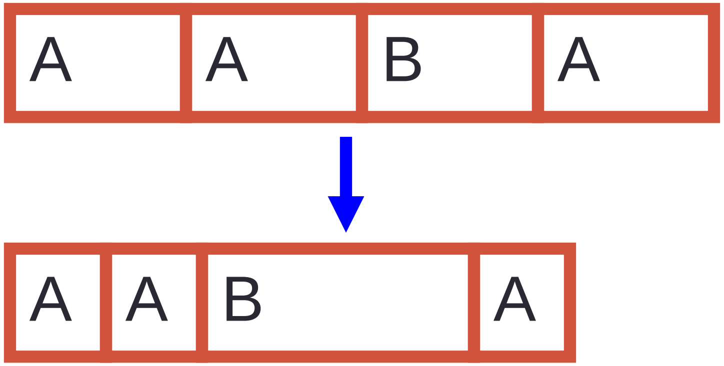
- Lossless Compression is not guaranteed
  - Pigeonhole principle
    - Reduce size 1 bit $\Rightarrow$ can only store ½ of data
    - Example
      - 000, 001, 010, 011, 100, 101, 110, 111 $\Rightarrow$ 00, 01, 10, 11
  - If compression is always possible (alternative view)
    - Compress file (reduce size by 1 bit)
    - Recompress output
    - Repeat (until we can store data with 0 bits)

Lossless Compression Techniques

- LZW (Lempel-Ziv-Welch) compression
  - Build pattern dictionary
  - Replace patterns with index into dictionary
- Run length encoding
  - Find & compress repetitive sequences
- Huffman code
  - Use variable length codes based on frequency

Huffman Code

- **Approach**
  - Variable length encoding of symbols
  - Exploit statistical frequency of symbols
  - Efficient when symbol probabilities vary widely
- **Principle**
  - Use fewer bits to represent frequent symbols
  - Use more bits to represent infrequent symbols



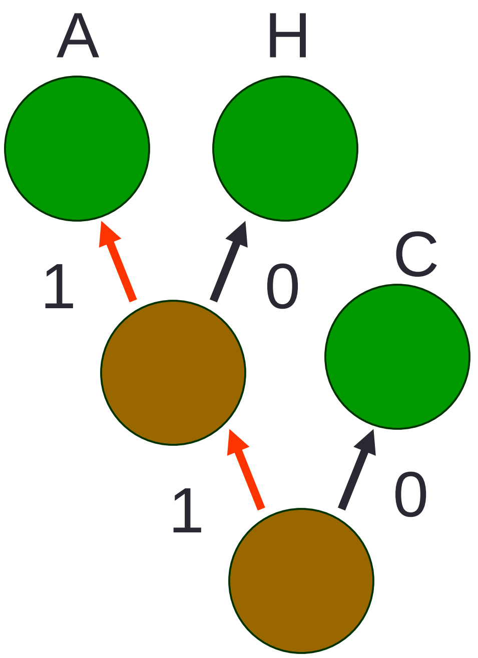
Huffman Code Example

Symbol	Dog	Cat	Bird	Fish
Frequency	1/8	1/4	1/2	1/8
Original Encoding	00	01	10	11
	2 bits	2 bits	2 bits	2 bits
Huffman Encoding	110	10	0	111
	3 bits	2 bits	1 bit	3 bits

- **Expected size**
  - Original $\Rightarrow 1/8\times2 + 1/4\times2 + 1/2\times2 + 1/8\times2 = 2$ bits / symbol
  - Huffman $\Rightarrow 1/8\times3 + 1/4\times2 + 1/2\times1 + 1/8\times3 = 1.75$ bits / symbol

Huffman Code Data Structures

- **Binary (Huffman) tree**
  - Represents Huffman code
  - Edge $\Rightarrow$ code (0 or 1)
  - Leaf $\Rightarrow$ symbol
  - Path to leaf $\Rightarrow$ encoding
  - Example
    - A = “11”, H = “10”, C = “0”
- **Priority queue**
  - To efficiently build binary tree



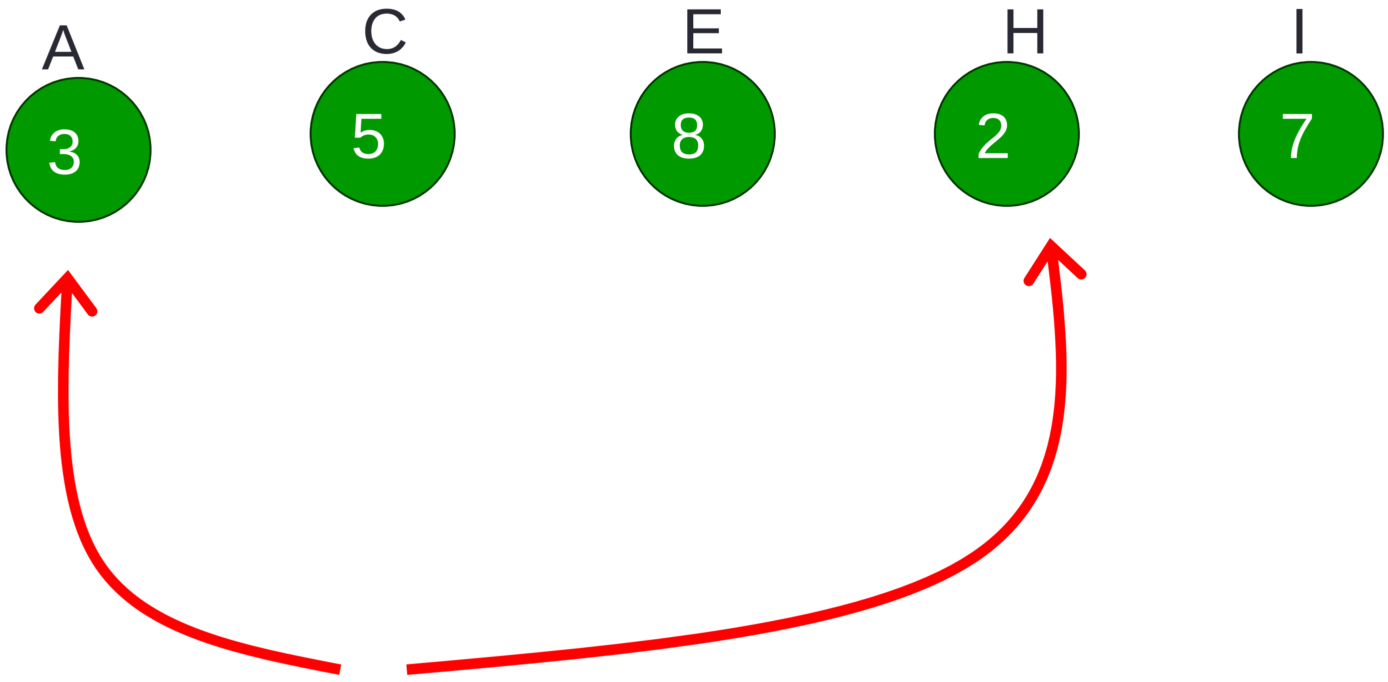
Huffman Code Algorithm Overview

- **Encoding**
  1. Calculate frequency of symbols in file
  2. Create binary tree representing “best” encoding
  3. Use binary tree to encode compressed file
     - For each symbol, output path from root to leaf
     - Size of encoding = length of path
  4. Save binary tree

Huffman Code – Creating Tree

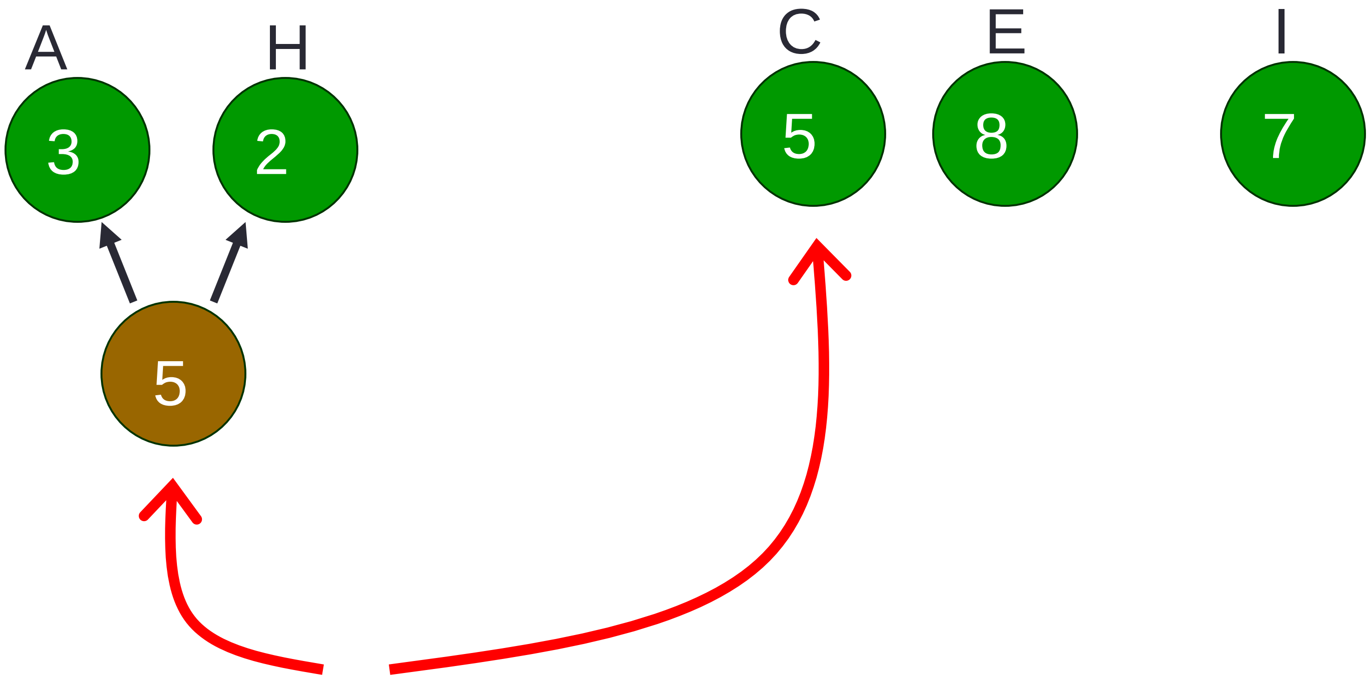
- **Algorithm**
  1. Place each symbol in leaf
     - Weight of leaf = symbol frequency
  2. Select two trees L and R (initially leafs)
     - Such that L, R have lowest frequencies in tree
  3. Create new (internal) node
     - Left child $\Rightarrow$ L
     - Right child $\Rightarrow$ R
     - New frequency $\Rightarrow$ frequency(L) + frequency(R)
  4. Repeat until all nodes merged into one tree

Huffman Tree Construction 1



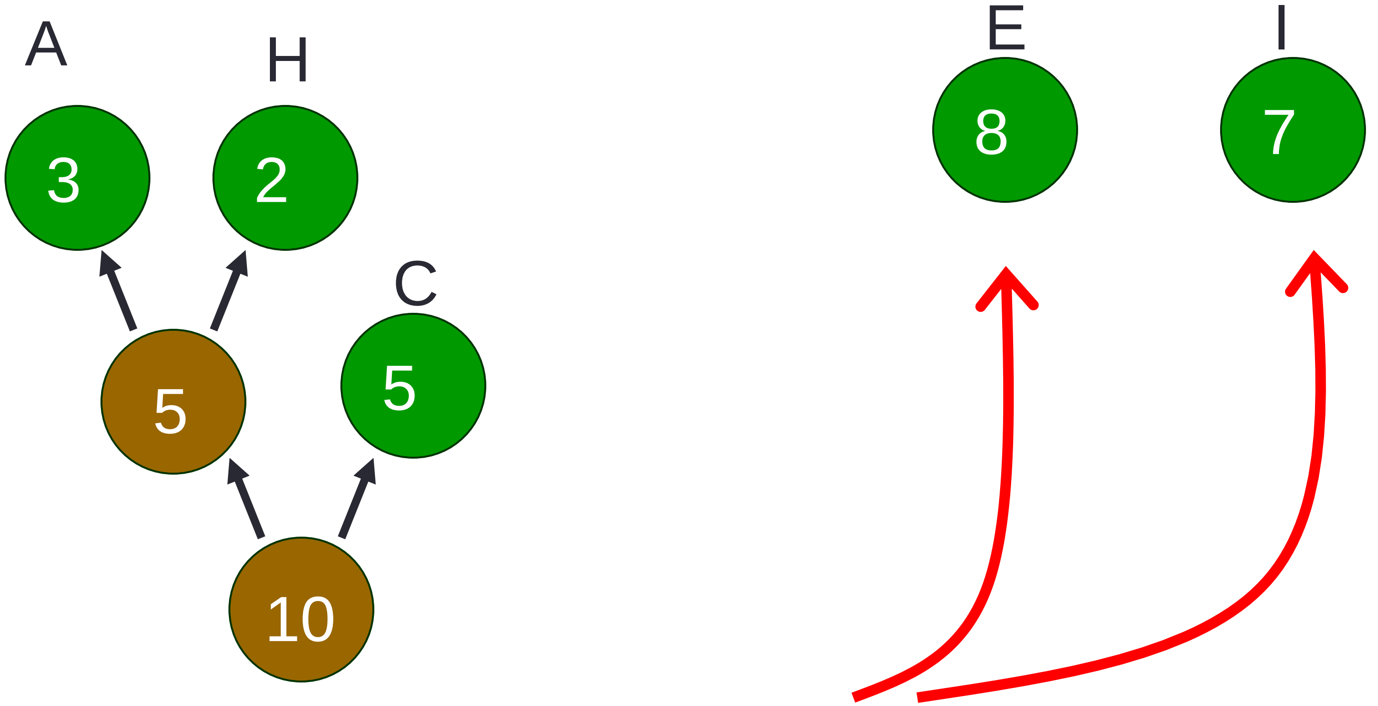
2 trees with lowest frequency

Huffman Tree Construction 2



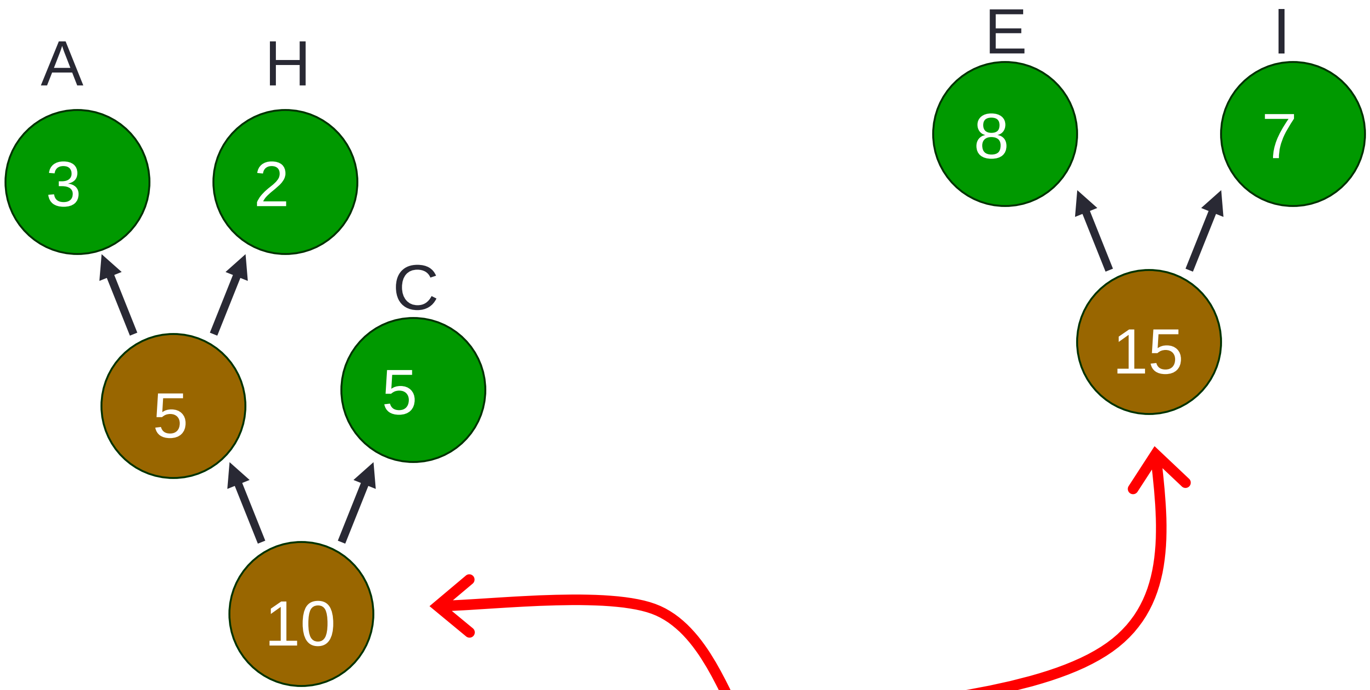
2 trees with lowest frequency

Huffman Tree Construction 3



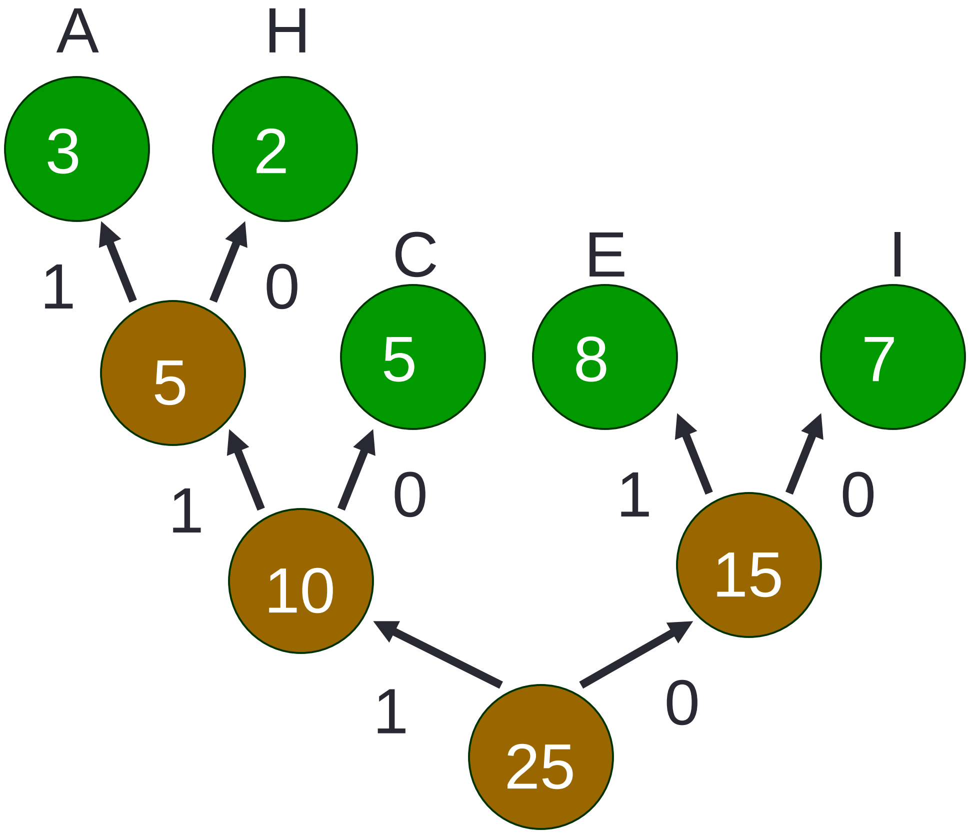
2 trees with lowest frequency

Huffman Tree Construction 4



2 trees with lowest frequency

Huffman Tree Construction 5



E = 01
I = 00
C = 10
A = 111
H = 110

Huffman code for each leaf

Huffman Coding Example

- **Huffman code**

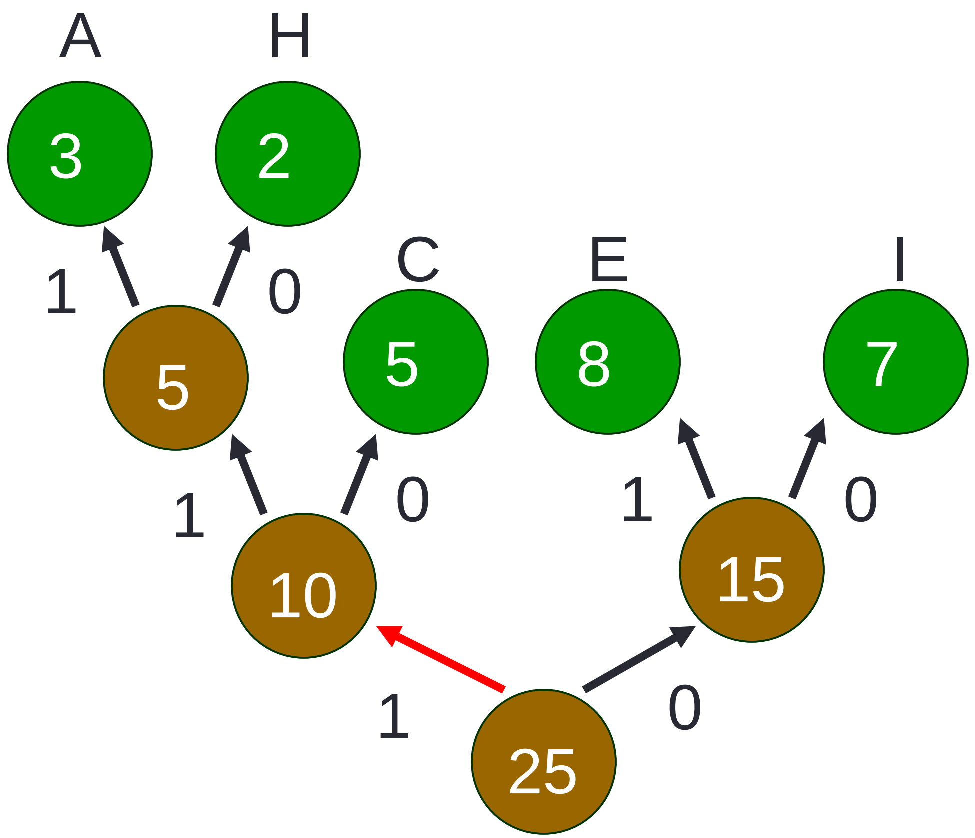
  E = 01
  I = 00
  C = 10
  A = 111
  H = 110

- **Input**
  - ACE
- **Output**
  - (111)(10)(01) = 1111001

Huffman Code Algorithm Overview

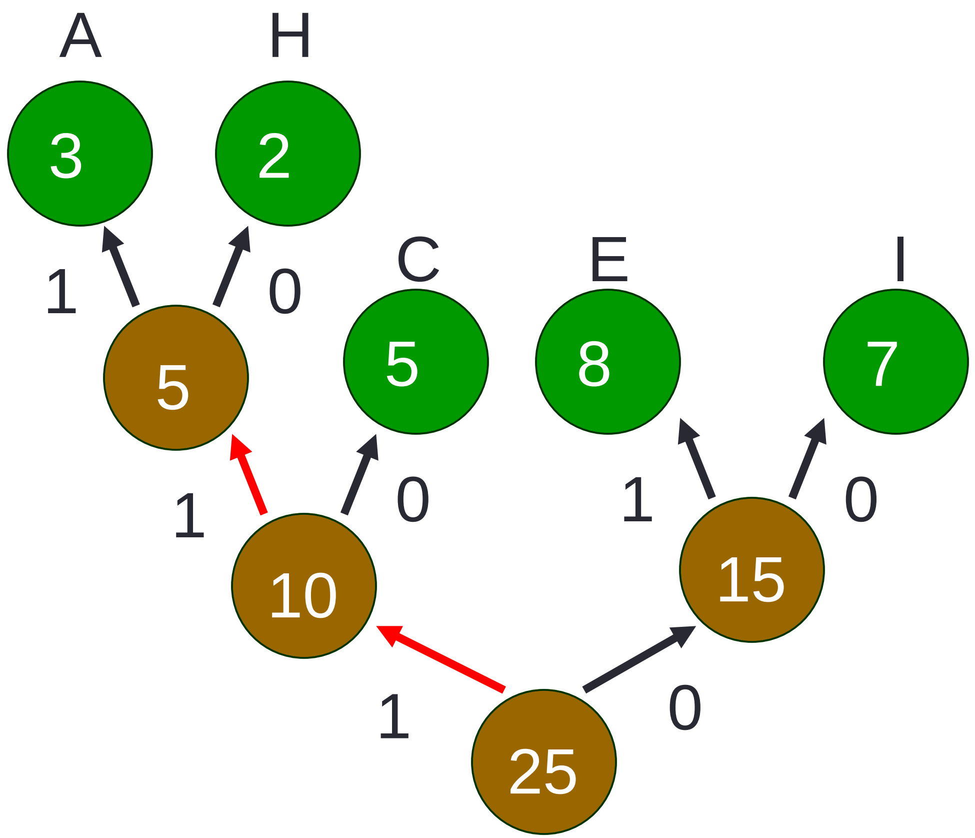
- Decoding
  1. Read compressed file & binary tree
  2. Use binary tree to decode file
     - Follow path from root to leaf

Huffman Decoding 1



1111001

Huffman Decoding 2



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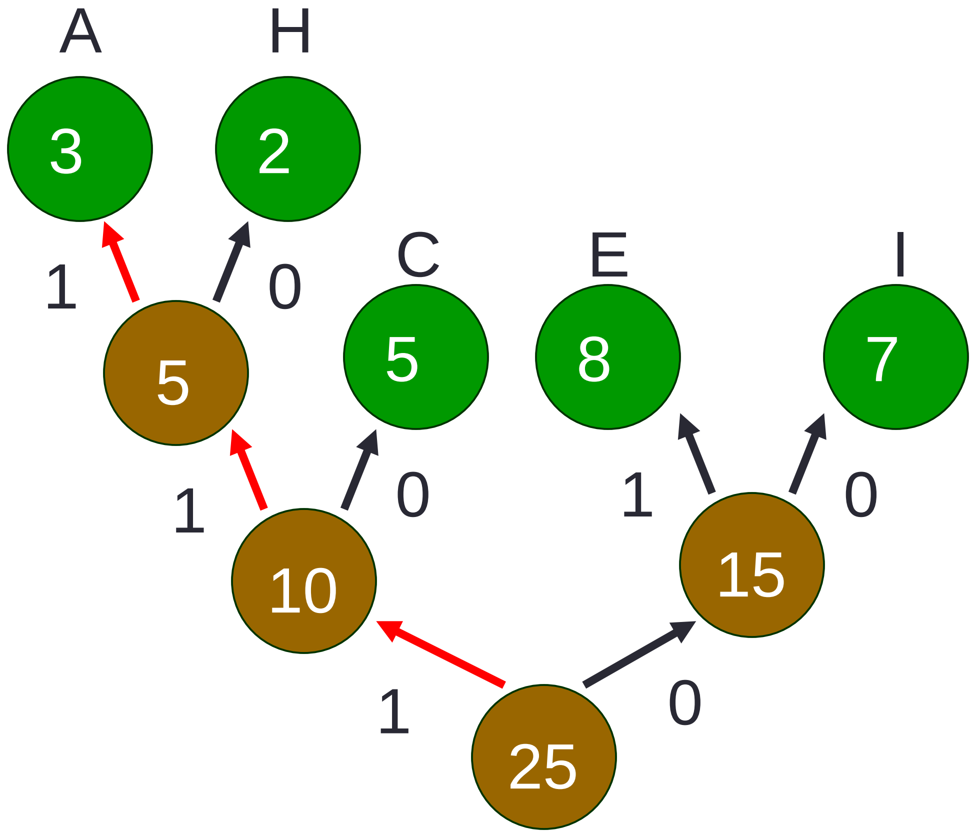
Huffman Decoding 3



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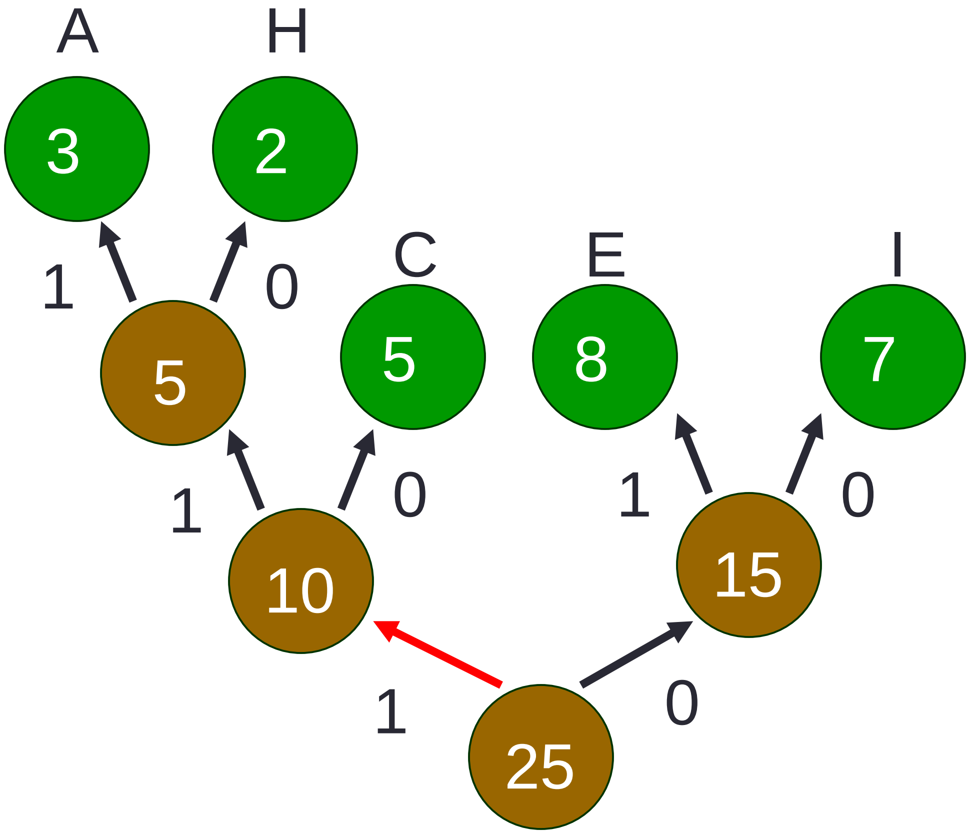
A

Huffman Decoding 4



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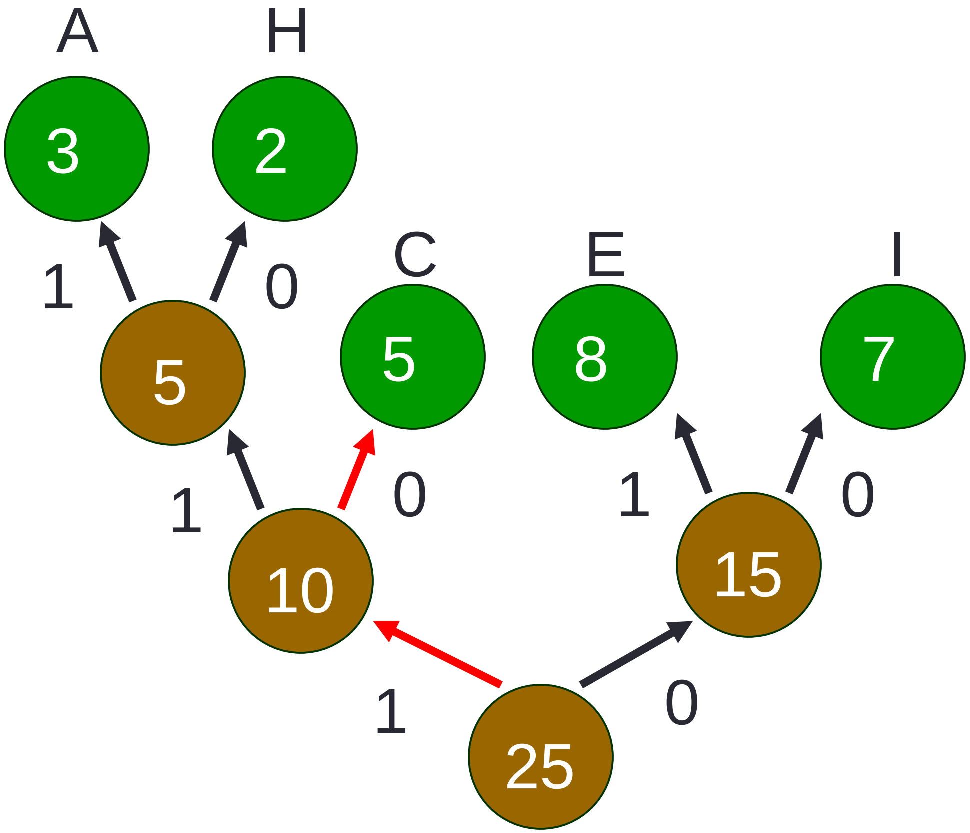
A

Huffman Decoding 5



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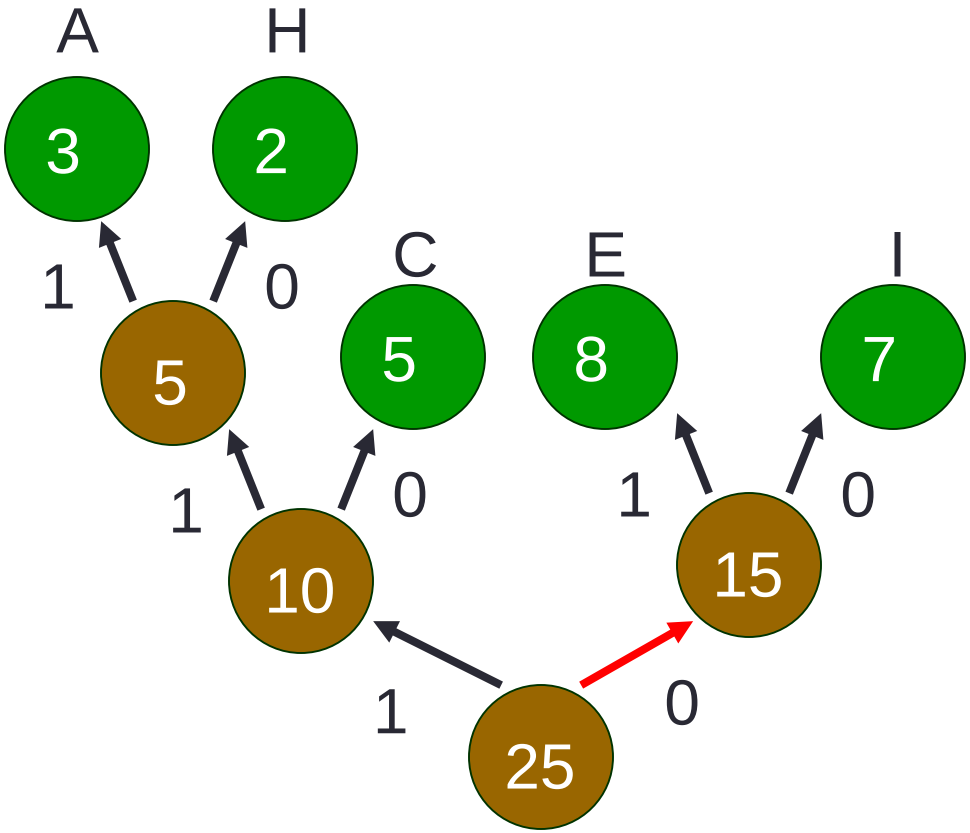
AC

Huffman Decoding 6



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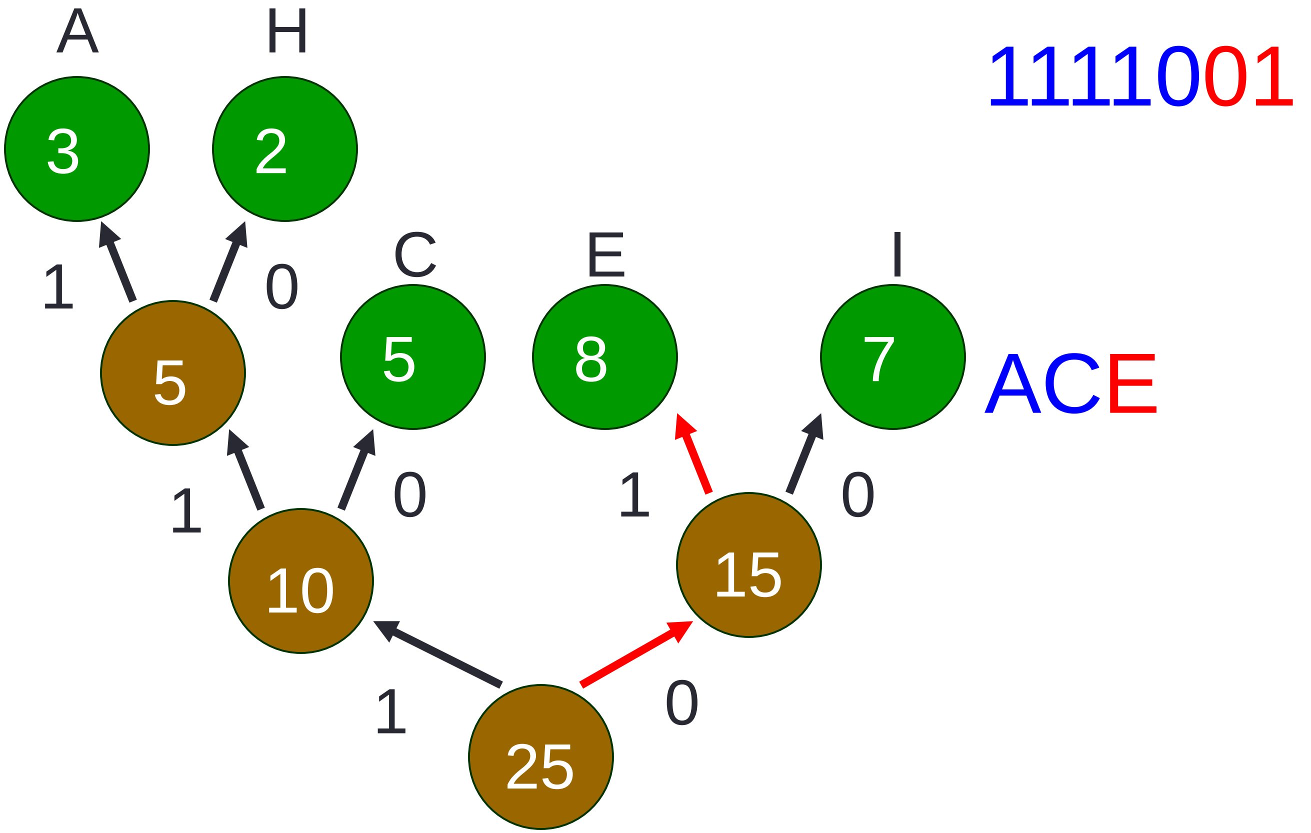
AC

Huffman Decoding 7



Huffman Code Properties

- **Prefix code**
  - No code is a prefix of another code
  - Example
    - Huffman("dog") $\Rightarrow$ 01
    - Huffman("cat") $\Rightarrow$ 011 // not legal prefix code
  - Can stop as soon as complete code found
  - No need for end-of-code marker
- **Nondeterministic**
  - Multiple Huffman coding possible for same input
  - If more than two trees with same minimal weight

Huffman Code Properties

- **Greedy algorithm**
  - Chooses best local solution at each step
  - Combines 2 trees with lowest frequency
- **Still yields overall best solution**
  - Optimal prefix code
  - Based on statistical frequency
- **Better compression possible (depends on data)**
  - Using other approaches (e.g., pattern dictionary)