Section 2: Week 5: Algorithm Implementation

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# Algorithm Implementation

The operating system’s file system is responsible for persisting bytes streams to disk and retrieving it at a later point. While this in a simple concept its actual implementation is foreign to me. File Allocation Tables (FAT) are an ideal starting point as (1) it shares many design patterns of modern file systems; (2) does this without all the bells and whistles. Afterwards a transparent compression feature was added to the implementation, based on Huffman Compression.

## File Allocation Tables (FAT)

When a file is created it will span one or more physical blocks on the disk drive. There are several reasons that can prevent a file from being written across a single continuous block sequence. For instance, the physical disk buffer the disk queue might interweave heavy disk I/O from multiple parallel processes. The file could also be too large and require fragmentation to fit.

To address these challenges FAT can be used to build a map of where each page of the file is located. Each entry in the FAT contains a pointer to the next entry that continues it, along with various metadata such as permissions and time stamps. The reader can then reassembly the file by traversing the linked list structure until an End of File (EOF) marker is detected.

## Huffman Compression

An obvious advantage of compressed data is that it is smaller and requires fewer resources. This can improve the performance of network transmissions and increases the available space on a disk drive. One method for implementing compression is with the Huffman Compression algorithm. It was invented in the mid- 50s as a mechanism for variable bit encoding, where the most frequently used characters use the least number of bits.

The algorithm begins by counting the frequency of each value within an input array. These counts are then used to build a sorted binary tree with individual byte values as the leaves. When traversing from the root to the leaf nodes, each branch is chosen as left or right. These decisions are encoded as binary values, and in turn becomes the code word for the compressed value.

For instance, if a leaf node has the value of letter T and is arrived through branches Left, Left, Right, and Left; then it would have a code word of 1101. If the value T was persisted in ASCII that would be 0101 0100 – twice the bit count.

Finally, a new output array is created and populated with metadata for reconstructing the code book. Next the input byte array is encoded and appended to output array. During decompression bits are decoded one-by-one through traversing the tree.

# Algorithm Efficiency

## FAT

To retrieve a file from FAT is efficient, taking time proportional to number of blocks containing the file. The system also leverages O(1) complexity for traversing the table. This is accomplished by creating all entries up front and then directly indexing into the entries array.

There is some overhead to finding the head of a file, especially in deep paths. The system must first request the root directory file, then parse the DirectoryEntry structures. These entries contain pointers to child DirectoryEntry objects which are stored in separate directory files. This process must recurse until eventually finding the requested file head.

There can also be challenges with finding a free location to write the page. The worst case would occur when the disk is full, and all FAT Entries need to be checked. Typically, there are dirty pages or available locations to keep the amortized cost down.

## Huffman Compression

One of the key challenges to the Huffman algorithm is that it needs to perform two passes through the input byte array. This is acceptable for most short messages but would not be useful across enormous files such as Virtual Hard Disk (VHD). The tree can have up to 255 (2^8) leaves. This can lead to a lot of required comparisons as it decodes one character at a time. A previous example described encoding the letter ‘T’ as 1101, which would require 4 branching decisions before reaching the leaf.

# Improving the Algorithms

## FAT

The FAT algorithm does not consider the physical movement of the disk controller arm. This can be expensive on mechanical disks as it needs to seek across the disk to reassembly the file. The Linux file system ext3 addressed this by adding a journaling feature which buffers huge memory segments to the disk. Later a background operation redistributes the journal contents to more optimal locations.

Another potential improvement is to redesign the Directory Entry files so that the recursive traversal is not needed. Perhaps the system could preemptively read directory files that are frequently accessed and likely to be queried.

The example implementation uses a dirty pages queue that is populated by the DeleteFile operation. This improves the WriteFile operation as it can quickly find an available page before performing a more expensive disk scan.

## Huffman Compression

One of the limitations of Huffman Compression is that it only encodes a single value at a time. Instead it could focus on multi-byte sequences to further improve compression rates. It would also be more efficient to only pass through the data once, like many stream compressors. This could be accomplished by determining the frequency weights ahead of time. For example, if the use case is predominately English text then ‘e’ will be more frequently used than ‘z’. The final compression might not be the perfectly efficient, though it would allow for larger data sizes.

# Issues and Observations

Implementing the Huffman algorithm was a little challenging due to the multiple transformation steps required. This was addressed by using the dynamic programming approach and placing a method stub anywhere that was not defined. By breaking down the description into smaller and smaller concise problems it was possible to continue making progress.

Given more time it would have also been nice to redo the compression algorithm in a low-level language like C, instead of C#. This is because the algorithm makes heavy use of bits and pointer mathematics.

The Linux kernel includes a reference implementation of FAT which leverages libfs to expose a lightweight file system. In a later course that focuses on operating systems specifically, it could be useful to revisit this area.

# Resources

Cantrell, G. (2014, October 30). *FAT File System Explained.* Retrieved from YouTube: https://www.youtube.com/watch?v=HjVktRd35G8

Georgia Tech. (2016). *File Allocation Table.* Retrieved from YouTube: https://www.youtube.com/watch?v=V2Gxqv3bJCk

Minnaard, W. (2014). The Linux FAT32 allocator and file creation order reconstruction. *Digital Investigation 11*, 224-233.

Sedgewick, R. (2014). *Algorithms, Fourth Edition.*