Method and Apparatus for multiple bit encoding and decoding of data through use of tree-based codes

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A decoder/encoder apparatus is provided which can be programmed to decode data and to encode data. To encode data, a memory within the apparatus is preloaded with a first memory map which is descriptive of a selected tree-based binary code. The first memory map is a reverse tree representation of the selected tree-based binary code. Data is then provided to the apparatus and is processed as specified by the first memory map thus generating encoded data. To decode data, the same memory is preloaded with a second memory map which is descriptive of the same selected tree-based binary code. The second memory map is a tree representation of the same selected tree-based binary code. Encoded data is then provided to the apparatus and is processed as specified by the second memory map thus generating decoded data.

10 Claims, 4 Drawing Sheets
FIG. 1
(PRIOR ART)

FIG. 2
(PRIOR ART)

FIG. 8
FIG. 6
METHOD AND APPARATUS FOR MULTIPLE BIT ENCODING AND DECODING OF DATA THROUGH USE OF TREE-BASED CODES

BACKGROUND OF THE INVENTION

This invention relates in general to encoding and decoding devices and, more particularly, to devices and methodology which are employed for data compression and decompression of binary codes.

Many recent advances have been made in data storage and communications media. However, the explosive proliferation of information and the continuous growth of data applications are outgrowing technological advances in storage devices and communication tools. Data compression offers an attractive approach to alleviate many of the problems associated with data proliferation. Among its many benefits are reduction in data storage requirements, reduction in the cost of communication within distributed networks, reduction in the cost of backup and recovery in computer systems, increased security and efficient search operations on compressed index structures of files. In recent years, the demand for data compression and the need to develop faster and more efficient compression methods have increased considerably due to the increased usage of data compression with scientific and statistical databases, document delivery systems and communication networks.

SUMMARY OF THE INVENTION

Accordingly, one object of the present invention is to provide an encoder/decoder apparatus which operates sufficiently fast that real time compression or decompression can be achieved.

Another object of the present invention is to provide an encoder/decoder apparatus that can be programmed to encode and decode different binary codes.

In accordance with the present invention, a method is provided for encoding data in an encoder including a memory having a plurality of memory locations containing data for simultaneous generation of multiple bits of tree-based binary codes in a single memory access cycle. The method includes the step of preloading the memory with a memory map descriptive of a selected multiple bit tree-based binary code, the memory map being a reverse tree representation of the selected multiple bit tree-based binary code. The method further includes the steps of providing data to the encoder, and encoding multiple bits of the data in each memory access cycle as specified by the memory map to generate encoded data. The preloading step includes loading an encoding tree into the memory, the encoding tree including a root node and a plurality of leaf nodes. The leaf nodes are mapped into the memory locations within the memory in one to one correspondence therewith.

BRIEF DESCRIPTION OF THE DRAWINGS

The features of the invention believed to be novel are specifically set forth in the appended claims. However, the invention itself, both as to its structure and method of operation, may best be understood by referring to the following description and accompanying drawings in which:

FIG. 1 is a single bit tree representing a variable length binary code using a prior art single bit process;
FIG. 2 is a prior art reverse binary tree for the tree of FIG. 1;
FIG. 3 is a 2 bit tree of the present invention corresponding to the 1 bit tree of FIG. 1;
FIG. 4 is a 2 bit reverse tree of the present invention corresponding to the 1 bit reverse tree of FIG. 2;
FIG. 5 is a 2 bit tree of the present invention for a Fibonacci code;
FIG. 6 is a schematic diagram of the architecture of the decoder/encoder apparatus of the present invention;
FIG. 7 is a reverse tree for the tree of FIG. 5; and
FIG. 8 is a block diagram of a communications network employing the decoder/encoder of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Before discussing the decoder/encoder apparatus of the present invention in detail, it is helpful to first understand the tree-based binary codes which the decoder/encoder apparatus employs. The term “tree-based” code means the set of codings which can be represented by a binary tree such as that shown in FIG. 1, for example. The letter characters a, b, ..., g located at leaf nodes 2, 6, 7, 8, 9, 10 and 12 represent the symbols to be encoded in accordance with the particular selected code. The root of the tree is designated as root 15. The sequence of 1's and 0's in the unique path from root 15 to a leaf node represents the unique code for that symbol. The relationship between the symbol and corresponding codes of the tree in FIG. 1 will be made clear by Table 1 below.

<table>
<thead>
<tr>
<th>a</th>
<th>010</th>
</tr>
</thead>
<tbody>
<tr>
<td>b</td>
<td>011</td>
</tr>
<tr>
<td>c</td>
<td>100</td>
</tr>
<tr>
<td>d</td>
<td>00</td>
</tr>
<tr>
<td>e</td>
<td>101</td>
</tr>
<tr>
<td>f</td>
<td>110</td>
</tr>
<tr>
<td>g</td>
<td>1110</td>
</tr>
</tbody>
</table>

In accordance with the code embodied in the binary tree of FIG. 1, the character or symbol “a” is represented by the code 010. This is derived by starting at the root node 15 and traversing the shortest direct path to the leaf node which represents “a”, namely leaf node 6. When traversing this path from root node 15 to leaf node 0 to leaf node 3 and then finally to leaf node 6, it is observed that the corresponding code is 010. This
In a similar manner, to determine the code which represents the symbol "g", we start at root node 15 and proceed along the shortest direct path to the leaf node which represents "g", namely leaf node 12. In so doing it is again observed that the code for the symbol "g" is 1110. This again confirms the symbol-code relationship shown in Table 1.

Tree based codes represent a large class of instantaneously decodable variable-length encoding schemes such as Huffman codes, Shannon-Fano codes, universal codes of Elias, the Fibonacci codes and the like. It is noted that the code depicted in the tree diagram of FIG. 1 is a variable length Huffman code.

To understand the compression/decompression apparatus and methodology of the present invention it is also helpful to understand reverse binary tree structures such as that depicted in FIG. 2. The binary tree of FIG. 2 is the reverse binary tree for the tree of FIG. 1. It is noted that the root in the reverse binary tree of FIG. 1 is different from root 15 of the binary tree of FIG. 1. The root of the reverse binary tree of FIG. 2 is labelled as root 12. The leaf nodes of the reverse binary tree are designated 0', 1', 2', ..., 11'.

The reverse binary tree is useful in encoding or compressing symbols. To encode a symbol in accordance with the reverse binary tree of FIG. 2, we start at a leaf node representing that symbol and then proceed along the shortest direct path to the root node 12'. For example, to encode the symbol "g", we start at leaf node 6' and then proceed to leaf node 5' and to leaf node 7' and to leaf node 10' and then to root node 12'. When traversing this path it is observed that the corresponding code to the symbol "g" is 1110.

For the purpose of developing multiple bit encoding and decoding schemes which will be discussed later in more detail, a k-bit tree associated with a code is now defined as follows: Each edge of such k-bit tree corresponds to the encoding of a maximum of k bits of the code. If the length of the code is n, it is represented by a sequence of [n/k] labels in the unique path from the root node to the leaf node of which only the last edge leading to the leaf node could possibly have a label with less than k bits. It will thus be appreciated that the tree of FIG. 1 is a 1 bit tree. The corresponding 2 bit tree for the same code is shown in FIG. 3. Stated alternatively, the 2 bit tree of FIG. 3 corresponds to the 1 bit tree of FIG. 1 and represents the same code. The 2 bit tree of FIG. 3 is read in substantially the same manner as the 1 bit code of FIG. 1, namely by starting at root 20 and traversing the shortest direct path to the symbols for which coding is desired. For example, to encode the symbol "g", we start at root 20 and then proceed to leaf node 25 and then to leaf node 30. In so doing, it is again observed that the code for the symbol "g" is 1110.

In a similar manner, a k bit reverse tree is defined. In the case of the k bit reverse tree, a sequence of 0's and 1's which are read from the leaf node to the root node specify the unique code for a particular symbol. The reverse binary tree of FIG. 2 represents a 1 bit reverse tree. FIG. 4 depicts the 2 bit reverse binary tree corresponding to the same code as the code represented by the reverse binary tree of FIG. 2. The algorithm to obtain a k bit reverse tree is very similar to the algorithm for the reverse binary tree and the complexity of the construction is linearly proportional to the total length of the binary codes of all the symbols.
a set of consecutive integers. Such a map is referred to as a "perfect map". In general, a perfect map is not always possible. For example, the sets \{M_1+0, M_1+1, M_1+2, M_1+3\}, \{M_2+0, M_2+2\} and \{M_3+0, M_3+1\} do not produce a perfect map. An acceptable or good map is one that maximizes the use of consecutive integers. Assuming that the map uses integers 0 through N-1 with W unassigned integers, the ratio W/N will be called the gap, g, of the map. It is noted that a perfect map exhibits no gap. The ratio (n-1)/N is defined to be the efficiency of the map. It will thus be appreciated that for a perfect map, g=0 and the efficiency=100%.

A sufficient condition for a perfect map is known. It is also noted that a 1 bit binary decoding tree has a perfect map. This is so because each non-leaf node of \(N_1, N_2, \ldots N_p\) has two children corresponding to labels 0 and 1. Assigning the first p even integers (i.e. 0, 2, \ldots, 2(p-1)) to the left child of \(N_1, N_2, \ldots N_p\) respectively will result in a perfect map.

FIG. 6 shows one embodiment of the decoder/encoder architecture of the present invention as decoder/encoder device 100. It is noted that this architecture combines both decoding and encoding features. The decoding feature of this architecture is now discussed.

For purposes of example it is assumed that it is desired to decode data which has been coded in accordance with the code represented in FIG. 5. Associated with the 2 bit decoding tree of FIG. 5 representing the selected code, a state machine is defined which includes the following hardware as shown in FIG. 6. The input string of data which is to be decoded can be shifted one or two bits at a time into register A (135). Each node except the root node of the decoding tree is mapped on to the memory locations in one to one fashion in memory 105 as given by the memory map Table 2.

TABLE 2

<table>
<thead>
<tr>
<th>MEMORY LOCATION</th>
<th>NEXT ADDRESS/SYMBOL</th>
<th>t</th>
<th>b</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Each memory word exhibits the format described as follows. If the memory location corresponds to a terminal symbol, then the symbol (or pointer to the symbol) is written in the symbol field and the least significant two bits t and b are set to 1 and 0, respectively.

TABLE 3

<table>
<thead>
<tr>
<th>ADDRESS/SYMBOL</th>
<th>t</th>
<th>b</th>
<th>f</th>
</tr>
</thead>
<tbody>
<tr>
<td>A regular non-terminal                          0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>A nonterminal with 2 backups                      0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A nonterminal with backup 0                     0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A nonterminal with backup 1                     0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>A terminal node                         1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The decoding method implemented by decoding/encoding device 100 is given below by the following steps.

Begin

Load Memory with Memory map table; MAR—start address of the map table
Initialize T, B and F
While (bit string to be decoded not exhausted) do

If \(F=0, B=0\): Shift two input bits to
\(a_1, a_2\)

If \(F=1, B=1\): shift one input bit to \(a_1\);
\(a_0=0\)

else: shift one input bit to \(a_1\)

if \(a_1=F\) then \(a_0=0\); else shift one input bit to \(a_0\)

end case

end

Fetch Memory word:
If \(T=1\) then (output symbol);
\(MAR\)—start address of memory map table;
Initialize T, B, and F again)
else \(MAR\)—MDR [11 \ldots 3];
\(F\)—MDR [0];
\(B\)—MDR [1];
\(T\)—MDR [2];

end
of the encoding process for that symbol. The next symbol is then read from the input buffer (not shown) coupled to the input of address decoder 175 and the entire process is repeated. The memory map for the reverse tree of FIG. 7 is shown below in Table 4. Table 4 is alternatively referred to as the encoder table.

<table>
<thead>
<tr>
<th>Present Address</th>
<th>Next Address</th>
<th>Encoded bit(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4</td>
<td>00</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>01</td>
</tr>
</tbody>
</table>

The decoder and encoder structures described above are advantageously combined together in a single architecture in the decoder/encoder device 100 of the present invention. In fact, in a preferred embodiment, these decoder and encoder structures are combined into a single VLSI chip including the circuit elements set forth in FIG. 6. To operate decoder/encoder device 100, the decoder 2 bit tree and its reverse tree are pre-loaded into memory 105. If there is any gap in the decoder memory map stored in memory 105, this memory space is utilized by the encoder memory map since many of its non-leaf nodes can be freely placed anywhere in memory 105. The beginning addresses of these tables are made available to the global control represented as control 195 in FIG. 6.

When the D/E (decode/encode) signal which is provided to demultiplexer (DMUX2) 117 is set to 1, device 10 acts as a decoder. If the D/E signal is set to 0, then device 100 acts as an encoder.

The decoder operation function as follows. Flip flops T, B and F are preset by reading a memory word from a specified location. The decoder control circuit 145 then generates a shift signal to read one or two bits from the input bit string received by shift register (A) 135. The input bit string is thus assembled into a number C that is added to the next address in adder 155. The demultiplexer (DMUX2) 117 selects t and b bits to the control which along with the f bit information is able to generate all local control signals. If a terminal symbol is reached, the demultiplexer (DMUX1) 16 sends the contents of memory data register (MDR) 115 (including the three least significant bits) to the output buffer (SYMBOL) 170. It will thus be appreciated that the hardware shown in FIG. 6 implements the steps of the decoding method discussed earlier.

The encoder operation functions as follows. For the encoding operation, the input symbols are used to access memory (MM) 105 via address decoder 175. The two least significant bits of the memory data register (MDR) 115 are selected for output to the FIFO register 180. The control flip-flop (L) 190, set by the length code detector 185, allows reading only one or two bits into FIFO register 180 depending on the length of the label in the reverse tree as discussed earlier. It is noted that during the encoding operation the adder circuit 155 can be bypassed since the next address is directly read from memory data register (MDR) 115. During encoding, the address computation and the memory access can be readily pipelined for successive pairs of bits to be decoded to achieve high throughput. Although a 2 bit implementation of decoder/encoder device 100 has been discussed above, device 100 is easily reconfigured to perform single bit decoding/encoding. Embodiments of the invention having bit widths other than 1 or 2 can also be implemented consistent with the teachings herein. To implement decoding/encoding of a 1 bit
such an embodiment, the addition cycle can be avoided for next address computation in the decoder by shifting the next address left one bit and by appending rather than adding, the terminal bit.

FIG. 8 shows a communications network which employs an encoder/decoder device 100 coupled via a communications link 200 to an encoder/decoder device 205 which is substantially identical to device 100. Communications link 200 is a wire-line, radio, optical, satellite microwave or other link which is capable of transmitting and receiving data. Each of devices 100 and 205 operate in the manner discussed earlier. The method of programming device 100 to encode and decode a particular type of binary code has already been discussed in detail. In the communications network of FIG. 8, each of decoder/encoder devices 100 and 205 are programmed to decode and encode the same code. In this manner devices 100 and 205 can communicate with each other. When device 100 is sending a message to device 205, device 100 encodes the message before sending the message over link 200 to device 205. When device 205 receives the message, device 205 decodes the message. Similarly, when device 205 is sending a message to device 100, device 205 encodes the message before sending the message over link 200 to device 100. When device 100 receives the message, device 100 decodes the message in the manner described earlier. As long as devices 100 and 205 are programmed to use the same binary code on each end of the link, devices 100 and 205 can communicate. It will be appreciated that other like decoder/encoder devices can be readily added to the communications network depicted in FIG. 8.

It is noted that the decoder/encoder device hardware described above is programmable in the sense that any tree-based code (Huffman, Shannon-Fano, Elias, etc.) can be implemented on the same hardware. The required preprocessing step includes preloading memory (MM) 105 with the appropriate memory maps for the particular selected code. In actual practice, memory maps for several different binary codes may be loaded simultaneously in memory. Switching from one code to another is accomplished by making the starting addresses of such different maps available to the control circuitry within device 100. In this manner, it is seen that the architecture of device 100 is readily adaptable to adaptive codes. More particularly, this is accomplished by employing a two port memory as memory 105. The write port of such two port memory is used to load to a different part of memory an updated memory map computed by a host processor (not shown, but coupled to device 100) based on the most recent statistics of the frequency of distribution of symbols. At appropriate intervals of time, the status of the read and write ports are switched thus adapting to new codes.

For an arbitrary k, the average height of the decoder tree will be reduced by a factor of 1/k and the size of the memory map will be decreased by a factor of k^l with an increase in word size by log^k additional bits. A speedup of k in the decoding/encoding process compared to the case of k = 1 will occur in most situations, where k bits are processed in each cycle, such as a memory access cycle in the case of a computer implemented process. It is noted that s = log_2 k bits b_1, b_2, ..., b_s are required to indicate the possibility of a potential backup with 0, 1, 2, ..., k−1 bits in the decoder and the same number of control bits L are required to indicate how many of the encoded bits represent valid output bits. The reading of the input bits to the input buffer (not shown) coupled to address decoder 175 can be handled by a shifter which can shift 1, 2, 3, ..., k bits, etc. Thus, even if it is assumed that the cost of control circuits is linearly proportional to k, a linear speedup in throughput can be achieved with a factor of 2 in savings of memory space.

While a method for encoding and decoding has been described above, it is clear that apparatus for encoding and decoding data has also been described. In summary, the encoder apparatus for encoding data includes a receiving circuit for receiving the data to be encoded. The encoder apparatus further includes a memory having a plurality of memory locations and a preloading circuit coupled to the memory. The preloading circuit loads the memory with a memory map which is descriptive of a selected tree-based binary code. The memory map thus loaded is a reverse tree representation of the selected tree-based binary code. The encoder apparatus further includes a processing circuit, coupled to the memory, for processing the data as specified by the memory map to encode the data, thus generating encoded data. The preloading circuit includes circuitry for loading an encoding tree into the memory wherein the encoding tree is a reverse tree including a root node and a plurality of leaf nodes. The leaf nodes are mapped into memory locations within the memory in one to one correspondence therewith.

Also in summary, the decoder apparatus for decoding data includes a receiving circuit for receiving data to be decoded and a memory including a plurality of memory locations. The decoder apparatus further includes a preloading circuit, coupled to the memory, for preloading the memory with a memory map descriptive of a selected tree-based binary code. The memory map is a tree representation of the selected tree-based binary code. The apparatus also includes a processing circuit, coupled to the memory, for processing the data as specified by the memory map to decode the data thus generating decoded data. The preloading circuit includes circuitry for loading a decoding tree into the memory, such decoding tree including a root node and a plurality of leaf nodes. The leaf nodes are mapped into memory locations within the memory in one to one correspondence therewith.

The foregoing describes a memory based decoder/encoder architecture and method of operation which are advantageously employed for the real-time compression/decompression of data. The decoder/encoder apparatus can be programmed to encode and decode different binary codes. The decoder/encoder device is readily fabricated in a VLSI implementation since the device employs standard modules such as a memory, adder, shift register, multiplexers and demultiplexers as building blocks. The speed at which the device encodes or decodes depends on the size of the memory employed. The decoder/encoder device may advantageously be employed in space communication, image data compression, and text and scientific data compression.

While only certain preferred features of the invention may have been shown by way of illustration, many modifications and changes will occur to those skilled in the art.
It is, therefore, to be understood that the present claims are intended to cover all such modifications and changes which fall within the true spirit of the invention.

What is claimed is:

1. A method for encoding data in an encoder, said encoder including a memory having a plurality of memory locations containing data for simultaneous generation of multiple bits of tree-based binary codes in a single memory access cycle, said method comprising the steps of:
   - preloading said memory with a memory map descriptive of a selected multiple bit tree-based binary code, said memory map being a reverse tree representation of said selected multiple bit tree-based binary code;
   - providing data to said encoder; and
   - encoding multiple bits of said data in each memory access cycle as specified by said memory map to generate encoded data.

2. The method of claim 1 wherein said preloading step comprises loading an encoding tree into said memory, said encoding tree being a multiple bit reverse binary tree including a root node and a plurality of leaf nodes, said leaf nodes being mapped into said memory locations within said memory in one to one correspondence therewith.

3. A method for decoding data in an decoder, said decoder including a memory having a plurality of memory locations, each memory location containing data for simultaneous decoding of multiple bits of a tree-based binary code in a single memory access cycle, said method comprising the steps of:
   - preloading said memory with a memory map descriptive of a selected multiple bit tree-based binary code;
   - providing data to said decoder; and
   - decoding multiple bits of said data in each memory access cycle as specified by said memory map to generate decoded data.

4. The method of claim 3 wherein said preloading step comprises loading a multiple bit binary decoding tree into said memory, said decoding tree including a root node and a plurality of leaf nodes, said leaf nodes being mapped into said memory locations within said memory in one to one correspondence therewith.

5. A method for decoding and encoding data in an decoder/encoder, said decoder/encoder including a memory, said method comprising the steps of:
   - preloading said memory with a memory map descriptive of a selected tree-based binary code, said first memory map being a multiple bit reverse tree representation of said selected tree-based binary code;
   - preloading said memory with a second memory map descriptive of said selected multiple bit binary tree-based binary code, said second memory map being a tree representation of said selected tree-based binary code;
   - providing first data to said decoder/encoder;
   - encoding said first data as specified by said first memory map;
   - providing second data to said decoder/encoder; and
   - decoding said second data as specified by said second memory map.

6. An encoder apparatus for encoding data comprising:
   - means for receiving data to be encoded;
   - a memory including a plurality of memory locations;
   - preloading means, coupled to said memory, for preloading said memory with a memory map descriptive of a selected tree-based binary code, said memory map being a multiple bit reverse tree representation of said selected tree-based binary code; and
   - processing means, coupled to said memory, for processing said data as specified by said memory map to encode said data.

7. The encoder apparatus of claim 6 wherein said preloading means further includes means for loading an encoding tree into said memory, said encoding tree being a multiple bit reverse tree including a root node and a plurality of internal and leaf nodes, at least some of said internal nodes and said leaf nodes being mapped into said memory locations within said memory in one to one correspondence therewith.

8. An decoder apparatus for decoding data comprising:
   - means for receiving data to be decoded;
   - a memory including a plurality of memory locations;
   - preloading means, coupled to said memory, for preloading said memory with a memory map descriptive of a selected tree-based binary code, said memory map being a multiple bit tree representation of said selected tree-based binary code; and
   - processing means, coupled to said memory, for processing said data as specified by said memory map to decode said data.

9. The apparatus of claim 8 wherein said preloading means further includes means for loading a decoding tree into said memory, said decoding tree including a root node and a plurality of leaf nodes, said leaf nodes being mapped into said memory locations within said memory in one to one correspondence therewith.

10. A decoder/encoder apparatus for decoding and encoding data comprising:
   - first receiving means for receiving first data to be encoded;
   - second receiving means for receiving second data to be decoded;
   - a memory;
   - first preloading means, coupled to said memory, for loading said memory with a first memory map descriptive of a selected tree-based binary code, said first memory map being a multiple bit reverse tree representation of said selected tree-based binary code;
   - second preloading means, coupled to said memory, for loading said memory with a second memory map descriptive of said selected tree-based binary code, said second memory map being a multiple bit tree representation of said selected tree-based binary code; and
   - processing means, coupled to said memory, for processing said first data as specified by said first memory map to encode said data and for processing said second data as specified by said second memory map to decode the data.
CERTIFICATE OF CORRECTION

PATENT NO. : 5,216,423
DATED : June 1, 1993
INVENTOR(S) : Amae Mukherjee

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, Item [75] Inventor should read:

-- Amar Mukherjee.--

Signed and Sealed this
Eighth Day of March, 1994

BRUCE LEHMAN
Attest: Commissioner of Patents and Trademarks

Attesting Officer