THE UNIVERSITY OF SYDNEY

COMP2017 / COMP9017 Assignment 3

Full assignment due: May 31st, 11:59 pm AEST (Week 13 Sunday)

Milestone due: May 24th, 11:59 pm AEST (Week 12 Sunday)

This assignment is worth 16% of your final assessment

Task Description

In this assignment, you will create a networked server ("JXServer") that sends files to clients in response to requests. Your server will support multiple connecting clients simultaneously as well as multiple simultaneous connections from the same client for increased transfer speeds.

Your assignment will also be tested for performance. You will need to correctly manage multiple parallel connections.

Milestone

To ensure you are making progress on this assignment, you need to complete a minimum amount of work by May 24th, 11:59 pm AEST (Week 12 Sunday) to receive up to 4 out of 16 total marks.

2 out of 4 milestone marks are for passing specified Milestone automatic correctness tests on Ed.

By the Milestone deadline, you must also submit in your assignment workspace on Ed, a 300 word description of your design of your assignment so far (please use a plain text file). This short description should outline the general logical flow of your assignment, including initial socket setup and including the method by which you are handling multiple connections. You may wish to include an example scenario of a client request and the flow of data on the network and in your program under this scenario.

You must attend your Week 13 tutorial, where you will have a short 5 minute discussion with your tutor as to your progress and the design of your assignment submission, with reference to your written description and last submission before the Milestone. See the Submission section at the end of this document for further details.

The written description and review by your tutor in your Week 13 tutorial will contribute the other 2 out of 4 milestone marks.

See the "Submission and Mark Breakdown" section at the end of this document for further information.

Working on your assignment

Staff may make announcements on Ed (https://edstem.org) regarding any updates or clarifications to the assignment. The Ed resources section will contain a PDF outlining any notes/changes/-corrections to the assignment. You can ask questions on Ed using the assignments category. Please read this assignment description carefully before asking questions. Please ensure that your work is your own and you do not share any code or solutions with other students.

You can work on this assignment using your own computers, lab machines, or Ed. However, it must compile and run on Ed and this will determine the grade. It is important that you continually back up your assignment files onto your own machine, flash drives, external hard drives and cloud storage providers, **ensuring that it is private, and only accessible by you**. You are encouraged to submit your assignment while you are in the process of completing it to receive feedback and to check for correctness of your solution.

Introduction

Typically, networking functionality is implemented by kernel space code. On Linux and other Unix-like operating systems, the kernel implements the various components required for networking, such as Wifi capabilities and the Internet Protocol. This is made available to userspace programs through special system calls, which interact with an abstraction known as a socket.

Sockets represent a connection to another endpoint on a network, but are analogous to file handles and are also described by a file descriptor. "Reading" from or "writing" to a socket corresponds to receiving or sending data over the network. However, as there are specialised operations that need to be performed with sockets, such as accepting or making connections to network destinations, there are special system calls that are generally used.

A full discussion of network stacks and protocols is out of scope for this unit. For this assignment, your server will use standard Transmission Control Protocol (TCP) connections on top of the Internet Protocol, version 4 (IPv4). This is a standard networking protocol combination for ubiquitous services such as HTTP which we use on the "World Wide Web".

The combination of TCP and IP(v4), as implemented and exposed to userspace by the kernel, permits the formation of network connections. We will not be using any other version of IP in this assignment. A client initiates a connection to a server. Both client and server endpoints are defined by an IP address, which in IPv4 is a 32 bit unsigned integer, as well as a TCP port number, which is a 16 bit unsigned integer. Once the server accepts the connection, the endpoints exchange data to setup a reliable connection. Data that userspace programs send into the socket, at either end of the connection, is delivered and made available for receiving by the userspace application at the other endpoint. TCP guarantees that data is delivered reliably and in order over varying network conditions. It also permits either endpoint to send data simultaneously to each other. However, it treats data as a continuous stream rather than discrete messages; that is for example if an endpoint sends 5 bytes then 10 bytes, the other endpoint will be able to read the data as it is received, with no indication that there was originally a break in sending 5 bytes in.

Your server is responsible for creating a "listening" TCP socket. This means that it waits for inbound TCP connections from clients.

In software development, you will often be required to program against third party APIs and libraries. To practice this skill, for this assignment you will need to refer to the manpages for system calls mentioned to determine how to employ them, though guidance will be provided in this specification.

To create your TCP socket, you need to use **`socket(2)`**. For the domain argument, please use **`AF_INET`**. For the type argument, please use **`SOCK_STREAM`**. You can leave the protocol argument as 0.

You then need to bind your TCP socket to an address using **`bind(2)`**. This assigns an IP address and TCP port to your end of the socket.

You may have seen IPv4 addresses represented in "dotted quad notation", such as "192.0.2.1", which is simply 4 8-bit integers extracted in order from the 32-bit address. You may wish to use **`inet_aton(3)`** to convert from dotted quad notation to the 32-bit integer representation, and **`inet_ntoa(3)`** to convert in the other direction.

Next, you need to specify that your TCP socket will be listening for incoming connections, using **`listen(2)`**.

Finally, you will wait for inbound connections on your socket using **`accept(2)`**. The kernel will queue for your program connections to the IP address and TCP port combination that you **`bind(2)`** to. When **`accept(2)`** returns, it creates a new socket which allows your program to communicate with this particular accepted connection. Your original socket remains listening for further connections that can be accepted with **`accept(2)`**.

Once you have a connected socket, you can send data to the other endpoint using **`send(2)`**, and you can receive any data the other endpoint has sent using **`recv(2)`**.

To close a socket, preventing further communication on it, you can use **`shutdown(2)`** and/or **`close(2)`**.

This is a very basic sequence of system calls. To support multiple simultaneous connections, you may wish to use concurrent programming, such as threads or processes. You may also wish to use mechanisms by which you can be informed when a connection is waiting or data can be read. These include **`select(2)`** and **`poll(2)`**.

Please note the distinction between host and network byte order. Network protocols, including the one in this assignment, generally send data such as integers in big-endian ("network byte order"), whereas your host system generally stores them as little-endian. To help you convert between byte orderings, please review the manpages **`byteorder(3)`**, **`bswap(3)`** and/or **`endian(3)`**. For the avoidance of doubt, where applicable, data in this assignment is to be sent as big-endian on the network.

Task

You will write your server in C, compiling to a single binary executable. It will accept exactly 1 command line argument as follows:

`./server <configuration file>`

The argument **`<configuration file>`** will be a path to a binary configuration file. The data of this file will be arranged in the following layout from the start:

- 4 bytes - the IPv4 address your server will listen on, in network byte order

- 2 bytes - representing the TCP port number your server will listen on, in network byte order
- All remaining bytes until the end of the file - ASCII representing the relative or absolute path to the directory ("the target directory"), from which your server will offer files to clients. This will not be NULL terminated.

The configuration file is binary, not plaintext, and does not have any delimiters or terminators (including newlines).

The full contents of an example configuration file, as a hexdump, are shown below:

```
c0 00 02 01 16 2e 2f 74 65 73 74 69 6e 67
```

The file is explained in order below:

- **`c0 00 02 01`** - 4 bytes which represent the IPv4 address "192.0.2.1" in network byte order
- **`16 2e`** - 2 bytes which represent the port number 5678 in network byte order
- **`2f 74 65 73 74 69 6e 67`** - 8 bytes of ASCII representing the string "/testing" which is the path of the target directory

Your server will listen for and accept connections from clients. Upon a successful connection, clients will send a number of possible requests, described in the below format. Please note that all integer fields are sent in network byte order. Your server should not send any data except in response to a client request.

When a client is finished making requests on a given connection, they will **`shutdown(2)`** the connection. There is no explicit disconnect command. When you detect this (refer to **`recv(2)`**), you should close that socket and clean up any associated data in your program.

All client requests and server responses consist of one or more structured series of bytes, called messages. Each message will contain the following fields in the below format:

- 1 byte - Message header; this describes details about the message as follows.
  - First 4 bits - "Type digit": A single hexadecimal digit that defines the type of request or response. It is unique for different types of messages.
  - 5th bit - "Compression bit": If this bit is 1, it indicates that the payload is compressed (see "Compression" section below). Otherwise, the payload is to be read as is.
  - 6th bit - "Requires compression bit": If this bit is 1 in a request message, it indicates that all server responses (except for error responses) must be compressed (see "Compression" section below). If it is 0, server response compression is optional. It has no meaning in a response message.
  - 7th and 8th bits - padding bits, which should all be 0.
- 8 bytes - Payload length; unsigned integer representing the length of the variable payload in bytes (in network byte order).
- Variable byte payload - a sequence of bytes, with length equal to the length field described previously. It will have different meanings depending on the type of request/response message.

The full contents of an example message, as a hexdump, are shown below. Note that it is a valid example of a message in this network protocol, but does not correspond to any meaningful request or response you actually have to implement in this assignment.

```
d8 00 00 00 00 00 00 00 07 ab ab ab ab ab ab ab
```

This message is explained in order below:

- `d8` - 1 byte message header. This is represented by the binary `11011000`.
  - `1101` - 4 bits representing the hexadecimal type `0xD`
  - `1` - 1 bit flag indicating this payload is compressed
  - `0` - 1 bit flag which means, if this message is a request, the response does not have to be compressed. If this message is a response, it has no meaning.
  - `00` - 2 bits of 0 padding
- `00 00 00 00 00 00 00 07` - 8 bytes representing the payload length 7 in network byte order
- `ab ab ab ab ab ab ab` - the 7 byte payload

On any single connection, clients will only send one request at a time, before waiting for the appropriate response. That is, after sending a request, the client will wait for the server to send a complete response before sending the next request. For some requests, the server will need to send multiple response messages. An example is file retrieval, where the server may need to send a file to the client split over many response messages. In this case, the client will wait until all appropriate response messages are received before sending the next request, if any.

Error functionality

If you receive a client request with invalid (unknown) type field, your server is to send back a response with type digit 0xf, with no payload (payload length field 0), and then close the connection. You should also send this error message if there are any other errors that arise in requests with valid request type fields. You are to also send back this error response if you receive a client request with a type field that must only be used in server response messages. Error messages are never compressed, even if the original request indicated compression is required.

Echo functionality

Clients may request an "echo". The request type digit will be 0x0. There will be an arbitrary sequence of bytes in the payload of the request.

In response to this request, your server is expected to send back a response with type 0x1. The payload of your response should contain the same payload you received in the request. Note that if the original request requires compression, then you need to compress the payload before returning it in the response. However, after decompression, the payload should be identical to the one you received.

Directory listing

The request type will be 0x2. There will be no payload and the payload length field will be 0. The client is requesting a list of all files in the server's target directory.

In response to this request, your server is expected to send back a response with type 0x3. The payload of your response should contain the filenames of every regular file in the target directory provided in the command line arguments to your server. (You do not have to return subdirectories, links, or any other type of entry other than regular files). The filenames can be returned in an arbitrary order.

These filenames are to be sent end to end in the payload, separated by NULL (0x00) bytes. Include a NULL (0x00) byte at the end of the payload. You will need to set the payload length appropriately. If the directory is empty, send a single NULL (0x00) byte as a payload.

File size query

The request type will be 0x4. The request payload will be a NULL terminated string that represents a target filename, for which the client is requesting the size.

In response to this request, your server is expected to send back a response with type 0x5. The payload of your response should contain the length of the file with the target filename in your target directory, in bytes, represented as a 8-byte unsigned integer in network byte order. If the requested filename does not exist, return an error response message (see "Error functionality").

Retrieve file

The request type will be 0x6. This is a request for part or whole of a file in your server's target directory. The payload will consist of the following structure:

- 4 bytes - an arbitrary sequence of bytes that represents a session ID for this request. Please see below for uniqueness requirements.
- 8 bytes - the starting offset of data, in bytes, that should be retrieved from the file
- 8 bytes - the length of data, in bytes, that should be retrieved from the file
- Variable bytes - a NULL terminated string that represents a target filename

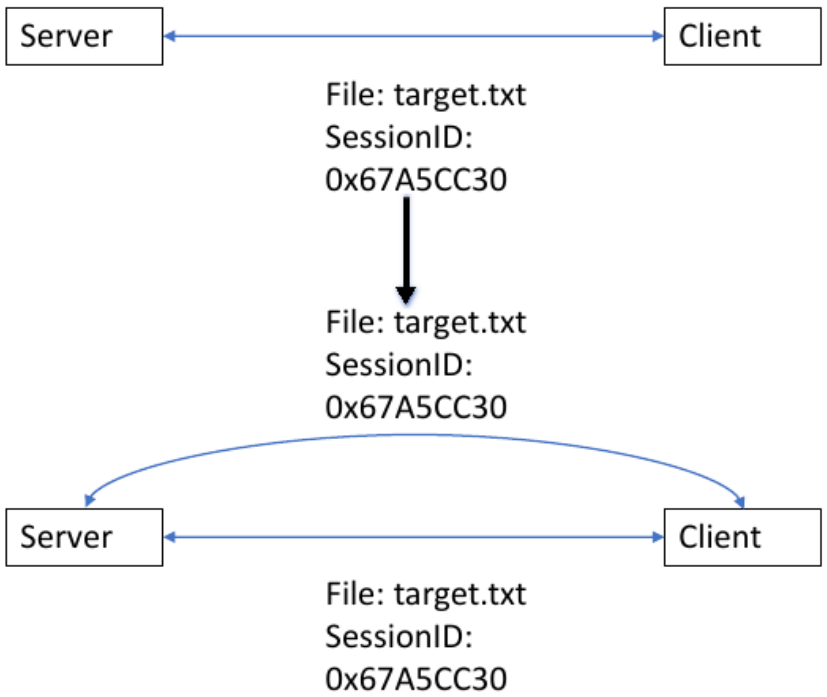
The filename will not contain any relative or absolute path components, you only need to search in the target directory, and no subdirectories.

In response to this request, your server is expected to send back one or more response messages with type 0x7. Each response of type 0x7 may represent a portion of the requested file data. It is up to you how many and how large these portions you send are. It is also up to you the order in which you send these portions; the start of the file does not need to be sent first, as long as all requested data is eventually received by the client. Different portions which you send corresponding to the same original request must not overlap in the byte ranges from the target file they contain. Each payload must consist of the following structure:

- 4 bytes - the same session ID as was provided in the original request
- 8 bytes - a starting offset of data, in bytes, from the target file, that this response contains
- 8 bytes - the length of data, in bytes, from the target file, that this response contains
- Variable bytes - the actual data from the target file at the declared offset and length in this response

The client may open several concurrent requests for the same filename on different simultaneous connections, with the same session ID. If you receive multiple connections with requests for the same file range with the same session ID, it means you are able to multiplex your file data across those connections; a single requesting client is unifying the data at the other end. If you choose to do this, you need to ensure that across all connections sharing the same session ID, the whole requested range of the file is eventually reconstructed. The client may make an extra concurrent connection for a given file at any time.

In the diagram below, the blue double headed arrows indicate a successful connection. Originally, the client has opened one connection, requesting the file target.txt, with session ID 0x67A5CC30. The client then opens a second connection, requesting the same file. Because the session ID is the same, the server accepts the connection, and is able to return file data simultaneously over the two connections (note that the requested file range must also be the same, but this is not shown in the diagram).

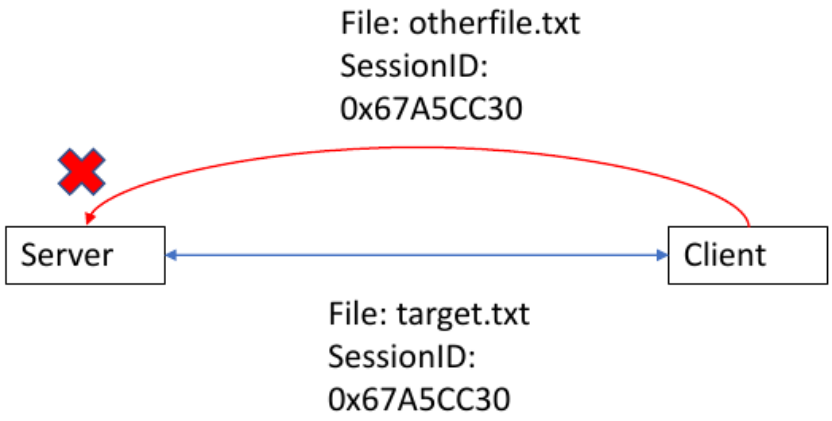


You do not have to multiplex your file response across multiple connections. If so, for connections on which you will not be returning data, you can send a response with type 0x7 with empty payload. However, your program must be returning the requested response on at least one connection among those the client opens.

If you would like to achieve higher performance, you will need to implement multiplexing of your file response across multiple connections.

It is not valid to receive a request for a different file, or the same file with a different byte range, with the same session ID as a currently ongoing transfer. If this occurs, you should send an error response message (see "Error functionality"). However, once the entirety of a file is transferred, the session ID may be reused for different files or the same file with a different byte range, in subsequent requests.

In the below example diagram, the red arrow indicates a failed connection where an error response should be sent. The client has an existing connection requesting the file target.txt, with session ID 0x67A5CC30. It has attempted to open a new connection requesting the different file otherfile.txt, with the same session ID. This is invalid; however the client is able to make a request for otherfile.txt, shown using the different session ID 0x1200CFBA. The server is then expected to service these two requests simultaneously.



You may receive a request for the same file with a different session ID while that file is being transferred under a first session ID. This is considered a separate client that requires a separate copy of the file and should receive the appropriate response.

If you receive any other invalid request, such as the filename not existing, or the requested byte range being invalid for the size of the target file, you must send an error response message (see "Error functionality").

Huffman coding

The client will send a request of type 0x8. This is a request for you to calculate and send the Huffman tree of a specified file in your server's target directory. This is intended to assist you with implementing Huffman coding for compression in the next section, where you will use the Huffman tree to generate "Huffman codes".

The request payload will consist of the following structure:

- Variable bytes - a NULL terminated string that represents a target filename. For the purposes of this section, you should always consider whole files.

In response to this request, your server is expected to send back one response with type 0x9. The response payload will consist of a variable series of segments in order, each of the same size. This series of segments encodes the Huffman tree, which is a binary tree. Leaf nodes store a "symbol" (more information provided below). Each segment represents a unique node in the tree and has the following structure in order:

- 2 bytes - unsigned integer that represents the ID of this segment. It must be unique among the segments in this payload. The root node of the tree must have ID 0x0000. Otherwise, the value is up to you.
- 2 bytes - unsigned integer that stores the parent ID of this node. For the root node, the parent ID must be 0x0000.
- 1 byte - unsigned integer that shows whether this child is a left or right child of the parent node. If it is 0x01, this is a left child; if it is 0x00, this is a right child. Any other value is invalid. For the root node, the value should be 0x00.
- 1 byte - unsigned integer that represents the "symbol" stored by this node, if and only if it is a leaf node. For this implementation of Huffman coding, symbols are single bytes (more information below). If this is an internal node, the value should be 0x00.

The term symbol refers to the possible values that input data can take on. In this case, we are considering arbitrary file data byte by byte. The symbols are therefore individual byte values, ranging from 0x00 to 0xFF.

To calculate your Huffman tree: firstly, determine the frequency of occurrence of each symbol in the input data. Create a node for each possible input symbol, with value equal to the frequency of that symbol. Subsequently, construct a binary tree using the following algorithm:

1. Choose the two nodes with smallest value. Form a new parent node, with these two nodes as children, with the child node having higher value to the left.
2. This new parent node has value equal to the sum of the values of its children. The parent node is now a node that can be chosen under this algorithm in step 1. The children are no longer eligible to be chosen in step 1.
3. Repeat steps 1-2 until there is only one node left. This is the root node of a binary tree that contains all original symbol nodes as leaves. This is the Huffman tree.

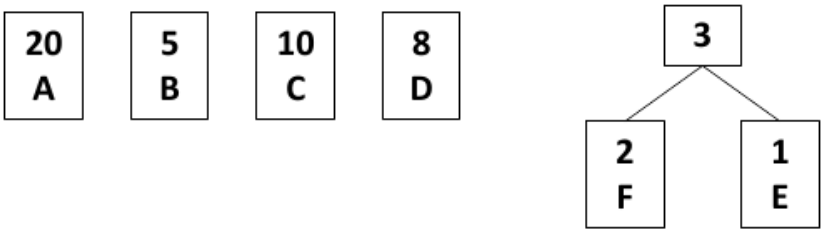
4. For each leaf, the Huffman code ("bit code") is determined by considering each edge to the leaf starting from the root node. All left edges add a "1" bit, and all right edges add a "0" bit.
5. For this assignment, if there is a tie in the value of nodes, the node or subtree with the lowest symbol value (byte value) is considered to have lower node value. The lowest symbol value of an internal node is considered to be the lowest symbol value among all leaves of the subtree rooted at that internal node.

An example of Huffman tree generation will now be described. In this example, the input data consists of only 6 possible "symbols": **`A B C D E F`** (in order of lowest to highest symbol value).

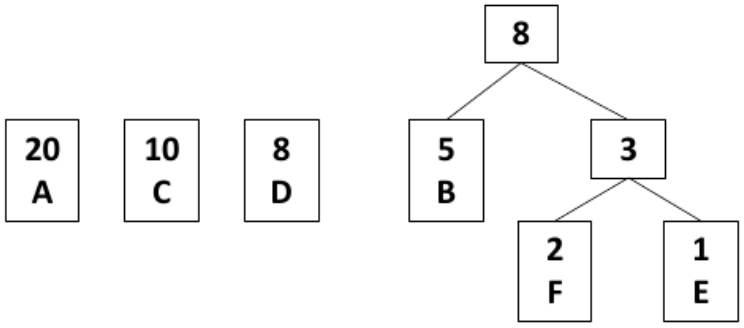
Suppose that the frequencies of these symbols are: **`A: 20, B: 5, C: 10, D: 8, E: 1, F: 2`**

Each symbol is represented by a node with value equal to the frequency.

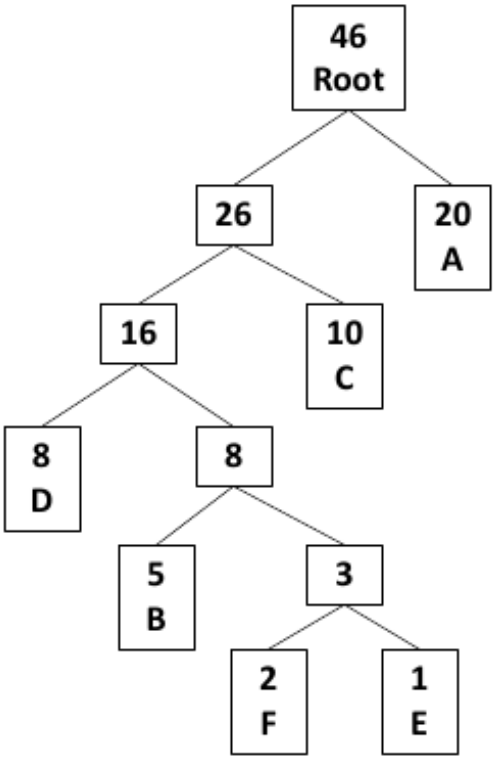
In the first step, pick two nodes with smallest value (E and F), and form a new parent node with these nodes as children. The new parent node has value (3) equal to the sum of the values of its children (1 and 2). The two child nodes can no longer be picked.



This new parent node has value 3, so we pick it and B (value 5) as the two smallest value nodes, to create a new parent node, with value 8.



Repeat this process until the entire tree is constructed. Note that a tie had to be broken when deciding whether to put the node corresponding to D on the left or the right. The internal node on the right has a subtree that contains lowest symbol value B, so it is considered to be lower value than D. Therefore, D is placed on the left.



An example of how this tree can be encoded in to the requested response payload follows (broken into new lines for ease of reading):

```
00 00 00 00 00 00
00 01 00 00 01 00
00 02 00 00 00 41
00 03 00 01 01 00
00 04 00 01 00 43
00 05 00 03 01 44
00 06 00 03 00 00
00 07 00 06 01 42
00 08 00 06 00 00
00 09 00 08 01 46
00 0A 00 08 00 45
```

Below, we show a breakdown of the first 18 bytes to demonstrate the format.

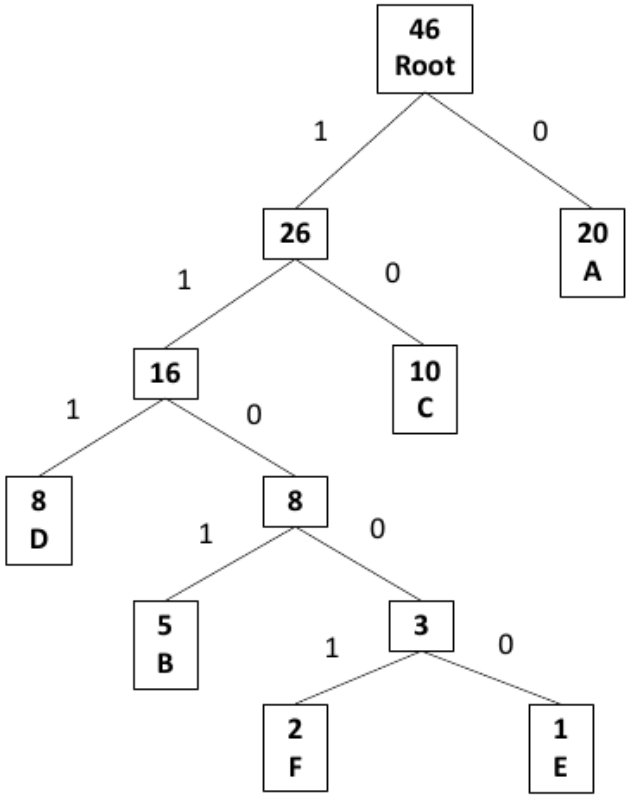
- `00 00 00 00 00 00` This is the root node (value 46 in the diagram), so it has ID 0x0000 and parent ID 0x0000, has 0x00 for left/right child, and 0x00 for the value of the symbol.
- `00 01 00 00 01 00` This is the internal node with value 26
  - `00 01` - We have assigned the ID 0x0001
  - `00 00` - It is a child of the parent ID 0x0000 (the root)
  - `01` - indicates it is a left child

  - `00` - because it is an internal node, the symbol value here is 0x00

- `00 02 00 00 00 41` This is the internal node with value 20
  - `00 02` - We have assigned the ID 0x0002
  - `00 00` - It is a child of the parent ID 0x0000
  - `00` - indicates it is a right child
  - `41` - In this case, we are simply using the ASCII code for A, which is 0x41. In this assignment, the symbol values can be any byte value.

Constructing the tree and encoding into the above format is all that is required for this section. However, for actually implementing compression for the next section, you will need to generate Huffman codes using the tree. Huffman codes are arbitrary length series of **bits** (not bytes). Each symbol used in tree construction is assigned a unique bit code.

Label each left edge in the tree with "1" and each right edge with "0". All input symbols are leaves of the tree. The bit code for each symbol is read by looking at the bit label of each edge to that leaf from the root.



The codes are therefore as follows: `A: 0, C: 10, D: 111, B: 1101, F: 11001, E: 11000`. Note that the most frequent symbols (A and C) receive the shortest bit codes. Additionally, note that this variable length code is uniquely decodable. This forms the basis of using Huffman coding for compression.

Huffman coding is a relatively easy to implement compression method which provides optimal or near-optimal compression under many circumstances, and guarantees the generation of a uniquely decodable dictionary.

Lossless Compression

For any message where the compression bit is set in the message header, the variable length payload is losslessly compressed, which means it is encoded in a way that completely retains the original payload information, but aims to reduce the size by applying a compression algorithm to the data. The payload will have the following structure in order (note that the sections are not necessarily aligned to bytes):

- Variable number of bits - Compression dictionary. See below for details. It is not necessarily aligned to a byte boundary.
- Variable number of bits - Compressed payload. See below for details. It is not necessarily aligned to a byte boundary.
- Variable number of bits - padding with 0 bits to the next byte boundary. This ensures that the structure is aligned to a byte boundary.
- 1 byte - an unsigned integer representing how many bits of 0 padding were required in the previous field

Note that the payload length field of the compressed message will contain the length of the compressed payload in bytes. Note that the padding in the compressed payload ensures it is aligned to whole bytes in size.

Your server may also receive request messages (which may also be compressed) where the "Requires compression" bit is set in the message header. This means that any message(s) that your server sends in response to such messages must be compressed. If this bit is not set for a request, then it is up to you whether to compress response(s) to that request. Your server should never set this bit in a response message; it is only valid in request messages.

The compression dictionary consists of 256 segments of variable length, each with the following structure. Each segment corresponds in order to the byte values from 0x00 to 0xFF. Because each segment is not necessarily aligned to a byte boundary, the entire compression dictionary is not necessarily aligned to a byte boundary.

- 1 byte - unsigned integer representing the length of this code in bits; this is equal to the length of the next field in bits. It is not necessarily aligned to a byte boundary.
- Variable number of bits - the bit code that is used to encode the byte value corresponding to this segment. It is not necessarily aligned to a byte boundary.

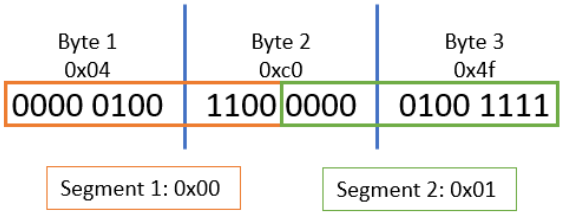
To create the compressed payload, for each byte in the original payload, obtain the segment in the compression dictionary corresponding to the byte value. In your compressed output, the bit code for this segment should be output for this input byte.

For compression to occur, some bytes must be encoded to bit codes that are shorter than one byte, whereas others will be encoded to bit codes that are longer than one byte. If those bytes encoded to shorter bit codes are more frequent in the input data, then overall, the compressed payload can be reduced in size.

An example of the start of a compression dictionary is shown below. Note that this only includes a few segments and the full dictionary would include all 256 segments:

```
04 c0 4f ...
```

This data is explained in order below:



- The first segment corresponds to the byte **`0x00`**
- **`04`** - the first byte is the length of the code for **`0x00`** in bits (i.e. 4 bits)
- **`c0`** - the binary for this byte is **`11000000`**. The first 4 bits, **`1100`**, is therefore the bit code for **`0x00`**. The next 4 bits is the start of the second segment, corresponding to the byte **`0x01`**. The size of the entire first segment for byte **`0x00`** is 12 bits.
- **`4f`** - the binary for this byte is **`01001111`**. Remember that segments are not necessarily aligned to byte boundaries. Therefore, the byte representing the length of the code for **`0x01`** is comprised of the second 4 bits from **`c0`** and the first 4 bits from **`4f`**. The binary is therefore **`00000100`**, which corresponds to a code length of 4 bits as well. This means that the second 4 bits of **`4f`**, **`1111`**, is the code for **`0x01`**.
- The size of the second segment is also 12 bits. Note that segments will vary in size. Depending on the size of each segment, the boundary of each segment can be at any bit offset within a byte, not necessarily 0 or 4 bits like in this short example. Remember that bit codes can be (much) longer than 8 bits. Some bytes necessarily "compress" to longer than a byte in order for overall data compression to occur.

Using just the segments shown in the example, you could compress data containing bytes **`0x00`** and **`0x01`**. For the following example uncompressed data:

```
01 00 00 01 01 00
```

Simply replace each uncompressed byte with the bit code from the compression dictionary. That is, the compressed binary would be:

```
1111 1100 1100 1111 1111 1100
```

This would result in the final compressed bytes:

```
fc cf fc
```

The compressed payload is immediately appended to the compression dictionary, with no regard for byte alignment. However, at the end of the compressed payload, there is 0-bit padding to the nearest byte boundary, and a single byte indicating how much padding there was (see above).

To decode compressed data, as you read in bits from the compressed payload, simply reverse the process by using the compression dictionary to find the original byte values. When you decompress a

payload, interpret that payload as per the other functionality of your server, depending on the message type digit contained in the message header.

For the "Requires compression" bit, you do not ever compress already compressed data. For example, if you receive an echo request with compressed payload, and "Requires compression" set, you should decompress the request to obtain the original echo payload, then compress the original payload before sending it in your response.

As you may note, input bytes are encoded to variable length bit codes ("variable length coding"). This raises the question of how a compressed data stream comprised of variable length codes can be decoded without knowledge of code boundaries. Your compression dictionary codes can be generated in a way such that they are **uniquely decodable** without knowledge of where a variable length code starts and ends. Huffman coding always generates such a compression dictionary.

It is strongly recommended that you use Huffman coding to generate your compressed dictionary and perform compression of your payload.

If you wish, for compression only, you can deviate from the exact Huffman algorithm, as long as you populate the compression dictionary data structure in the prescribed way. This gives you some limited flexibility to implement possible optimisations. Compression is important in improving performance in file transfer, by reducing the amount of data that is sent over the network. However, there are other considerations you need to make; for example, you also need to consider the time that it takes to compute the compressed payload, and if that is worth the decreased network transfer time.

However, for the Huffman tree request (request type 0x8), you cannot deviate from the Huffman algorithm specified.

In real-world systems, there are better ways to store Huffman codes than the compression dictionary construct, or different compression algorithms are used. However, for simplicity, you cannot make such changes in this assignment. The clients that test your server will expect compressed payloads in the specified format.

A comprehensive discussion of compression is beyond the scope of this course. You may wish to do further reading around information theory if you would like to learn more.

Notes and Hints

- For performance reasons, test clients will begin to make connections within approximately 1 second of your server startup. Please ensure that any setup you do is finished by this point, and your server is ready to accept connections. If your server is not ready to accept connections, you may receive a "Connection refused" error from the test client.
- You may find it helpful to use fixed-width integer types such as `uint8_t` and `uint64_t`
- When manipulating individual bits, you will find it helpful to review bitfields and/or bitwise operations.
- Depending on what your server is sending, the test client may not always be able to immediately validate the data sent. For example, if you declare a certain payload length, but only send part of it, the client may wait indefinitely for the remainder of the payload to be sent. There is no

timeout built into the assignment protocol. This means that you may receive a "ran too long" error due to inherent limits in the testing system.

Submission and Mark Breakdown

Submit your assignment via Git to Ed for automatic marking. Your server program will be executed, and automatic client programs will connect to it to carry out testing.

Your code will be compiled with the following options. Please note you may not use variable length arrays.

```
-O0 -Wall -Werror -Werror=vla -g -std=gnu11 -lm -lpthread -lrt -fsanitize=address
```

The mark breakdown of this assignment follows (**16 marks total**).

- **7 marks** for correctness, assessed by automatic test cases on Ed. Some test cases will be hidden and will not be available.
  - **2 mark** of these 7 correctness marks will be due for assessment at 11:59 pm AEST, Sunday May 24th as the Milestone. These will correspond to a subset of the final test cases, concerning starting your server, reading the configuration file, "Error functionality" and "Echo functionality" only (no compression required). Specifically, only test cases with names starting with `milestone` will count towards these marks. This will be assessed against your last submission before this Milestone time.
  - There will be no opportunity to regain this mark after the Milestone.
- **5 marks** for performance. This will assess the speed of your submission only. You must pass all correctness test cases before your submission will be assessed for performance.
- **4 marks** from manual marking by teaching staff.
  - **2 marks** of these 4 manual marks will be based on your 300-word description, which must be submitted before the Milestone deadline, combined with oral assessment by your tutor during your tutorial in Week 13.
  - There will be no opportunity to regain these marks after the tutorial assessment.
  - The other **2 marks** will be from manual marking by staff after the final assignment deadline. This will assess the style and structure of your code. Feedback will also be provided.

Warning: Any attempts to deceive or disrupt the marking system will result in an immediate zero for the entire assignment. Negative marks can be assigned if you do not follow the assignment specification or if your code is unnecessarily or deliberately obfuscated.

Academic Declaration

By submitting this assignment you declare the following:

I declare that I have read and understood the University of Sydney Student Plagiarism: Coursework Policy and Procedure, and except where specifically acknowledged, the work contained in this assignment/project is my own work, and has not been copied from other sources or been previously submitted for award or assessment.

I understand that failure to comply with the Student Plagiarism: Coursework Policy and Procedure can lead to severe penalties as outlined under Chapter 8 of the University of Sydney By-Law 1999 (as amended). These penalties may be imposed in cases where any significant portion of my submitted work has been copied without proper acknowledgment from other sources, including published works, the Internet, existing programs, the work of other students, or work previously submitted for other awards or assessments.

I realise that I may be asked to identify those portions of the work contributed by me and required to demonstrate my knowledge of the relevant material by answering oral questions or by undertaking supplementary work, either written or in the laboratory, in order to arrive at the final assessment mark.

I acknowledge that the School of Computer Science, in assessing this assignment, may reproduce it entirely, may provide a copy to another member of faculty, and/or communicate a copy of this assignment to a plagiarism checking service or in-house computer program, and that a copy of the assignment may be maintained by the service or the School of Computer Science for the purpose of future plagiarism checking.