Conversion of a Music Macro Language Variant to MIDI

Analysis

Background to Problem

The MIDI file format is a widespread and established standard for storing music. The music macro language (MML) is a niche language for describing music in a comparable way to how music is stored in MIDI files. It has no real standards, but has evolved over the years into different versions, the use of which are provided by BASIC implementations. One of the key issues with the MML is how there is not much software available that can play it; another issue is that the MML is, by design, only suited for monophonic tracks.

This project seeks to tackle both of these issues by providing a facility that can convert a number of files containing a music description language similar to MML into a single multi-channel MIDI file. This allows the benefits of both the MML and MIDI formats to be taken advantage of – music is easily entered with MML, and it is easily playable using the MIDI format.

Research Methods

The MIDI Specification

The first thing I have researched for this project is the specification of MIDI files.

Values in MIDI files are either stored as big endian binary numbers or as big endian variable length quantities.

MIDI files are composed of "chunks", which all consist of, at least, a 4-byte string, identifying the type of chunk, and the length of the chunk as a 32-bit integer. There are two different types of chunks featured in the MIDI specification 1.1 – header chunks and track chunks.

The following table shows how headers chunks are structured:

Bits 0-7	Bits 8-15	Bits 16-23	Bits 24-31
The ASCII characters "MThd"			
Length			
Format		Ntrks	
Division			

"Length" is a 32-bit unsigned integer describing how many bytes are left of the chunk. It is always 6 for a header chunk.

"Format" is a 16-bit unsigned integer that describes the format of the MIDI file. It can currently take three values:

Format	Description
0	The MIDI file is composed of a header chunk and a single track chunk
1	The MIDI file is composed of a header chunk and multiple track chunks that are to be played simultaneously
2	The MIDI file is composed of a header chunk and multiple track chunks that are to be played independently

"Ntrks" is a 16-bit unsigned integer that indicates how many track chunks there are in the file.

"Division" is a 16-bit unsigned integer that sets the meaning of the delta-times (which are variable length quantities put before every event, representing how long should be left from the end of the last event to the beginning of the current one).

The next table shows how track chunks are structured:

Bits 0-7	Bits 8-15	Bits 16-23	Bits 24-31
The ASCII characters "MTrk"			
Length			
MTrk Events ...			

"Length", like in the header chunk, is a 32-bit unsigned integer describing how many remaining bytes there are to be read in the chunk.

The rest of the track chunk consists of MTrk events, which are structured as follows:

<MTrk event> = <delta time> <event>

"Delta time" is a variable length quantity that represents the length of time to leave between this event and the last one.

"Event" can be one of three different varieties: MIDI, sysex and meta.

MIDI events are MIDI channel messages, such as note down and note up.

Sysex (system exclusive) events are messages that are sent via the MIDI file, but are not related to the playing of it.

Meta events describe how the MIDI commands should be played, and give supplementary information about the track, such as its name and cues.

The MIDI events that will be relevant for the project are shown in the table below: "nnnn" is where the nibble representing the channel number the message is for is placed.

Status Byte	Data Bytes	Description
1000 nnnn	0kkkkkkk	Note off event – sent when a key is released.
	0vvvvvvv	0kkkkkkk is the note number. 0vvvvvvv is the velocity.
1001 nnnn	0kkkkkkk	Note on event – sent when a key is depressed.
	0vvvvvvv	0kkkkkkk is the note number. 0vvvvvvv is the velocity.
1100 nnnn	0ppppppp	Patch change – sent when the instrument is changed. 0ppppppp is the new patch number.

The meta events that will be used in the project are shown below.

Form (hex)	Description
FF 03 [length] [name]	Track name – this command contains the name of the track. [length] is the length of the name following, as a variable length quantity. [name] is an ASCII string.
FF 2F 00	End of track – always present at the end of track chunk.
FF 51 03 tttttt	Set tempo. "tttttt" is three bytes that represent the number of microseconds per MIDI crochet.
FF 58 04 nn dd cc bb	Time signature. "nn" is a byte representing the top of a traditional time signature. "dd" is a byte representing the bottom of a traditional time signature as 2^{dd}. "cc" is a byte setting the number of MIDI clocks per metronome tick. "bb" is a byte setting the number of demisemiquavers per 24 MIDI clocks (usually 8)

A full example of a MIDI file in hexadecimal is shown below, split up into a table with descriptions on each section.

4D 54 68 64	"MThd"
00 00 00 06	Length of header chunk
00 00	Format 0
00 01	One track
00 20	32 ticks per crochet
4D 54 72 6B	"MTrk"
00 00 00 2A	Length of track chunk
00 FF 58 04 04 02 18 08	Set time signature to 4/4. Set 24 MIDI clocks per metronome tick. Set 8 demisemiquavers per 24 MIDI clocks
00 FF 51 03 07 A1 20	Set tempo to 0x07A120 (500 000) microseconds per 24 MIDI clocks. This corresponds to 120 BPM in this context.
00 C0 30	Set channel 0 to patch number 48
00 C1 30	Set channel 1 to patch number 48
00 90 45 7F	Play note with MIDI number 69 (A4) on channel 0 with maximum velocity.
81 10 80 45 7F	Release note with MIDI number 69 (A4) on channel 1 with maximum velocity after a delta time of 0x90.
00 91 40 7F	Play note with MIDI number 64 (E4) on channel 1 with maximum velocity.
7F 80 40 7F	Release note with MIDI number 64 (E4) on channel 1 with maximum velocity after a delta time of 0x7F.
00 FF 2F 00	End of track

Development Tools and Method

There are many programming languages that would be suitable for this project, but I have chosen to go with C, as I am comfortable with it, and I feel that it is suitable, being a low-level language and the amount of byte-wise manipulation needed in this project.

Python would also have been a good choice because of how easy string manipulation is in it, which would make the processing of the input language more convenient.

I found two tools in my research that I have decided to use in this project to produce the parsing portions of the code – Lex and Yacc. Lex takes a C file containing regular expressions and code to execute upon matches, and Yacc, which works in conjunction with Lex, takes a C file containing Back-Naur form grammar and code to execute upon reductions.

To learn how to use Lex and Yacc, I've purchased an O'Reilly book on them, which I'll be using throughout the project. I anticipate that I'll be using them in a fairly conventional manner, so the examples provided in the book will likely prove very useful.

An alternative to using Lex and Yacc would be writing my own parser and lexer, which could potentially yield faster code, but would take a great deal longer to develop.

To compile my code, I will use makefiles in combination with GCC. This is a common practice for C development, and one I am comfortable with. The alternative is entering the GCC, Lex and Yacc calls every time compilation is performed, which could be very inconvenient.

Clang is another C compiler that could be used, which has many advantages over GCC, such as compilation speed, but I am used to using GCC and have it already available on the machines I will be developing the project on.

Description of the Current System

The current way to convert multiple music macro language like files into a single multi-channel MIDI file is to step through by hand and enter the information as if writing a new MIDI file. This is tedious, unreliable and slow.

Identification of Potential Users

There is a small, but dedicated, remaining group of musicians that still use the music macro language.

Identification of User Need and Limitations

Users will need to be able to use all of the syntax of the MML, as it would be difficult to enter music if even one feature was removed.

The users should not need to have any technical knowledge to use the solution.

The solution should be fast enough to keep up with a musicians work flow, otherwise this would be stifling for their creativity.

The syntax of the MML used by the solution should be at least similar to what already exists, so as to minimise the effort required by the user.

Data Flow Diagrams

The following flow chart shows how the solution to the problem should work in terms of file flow:
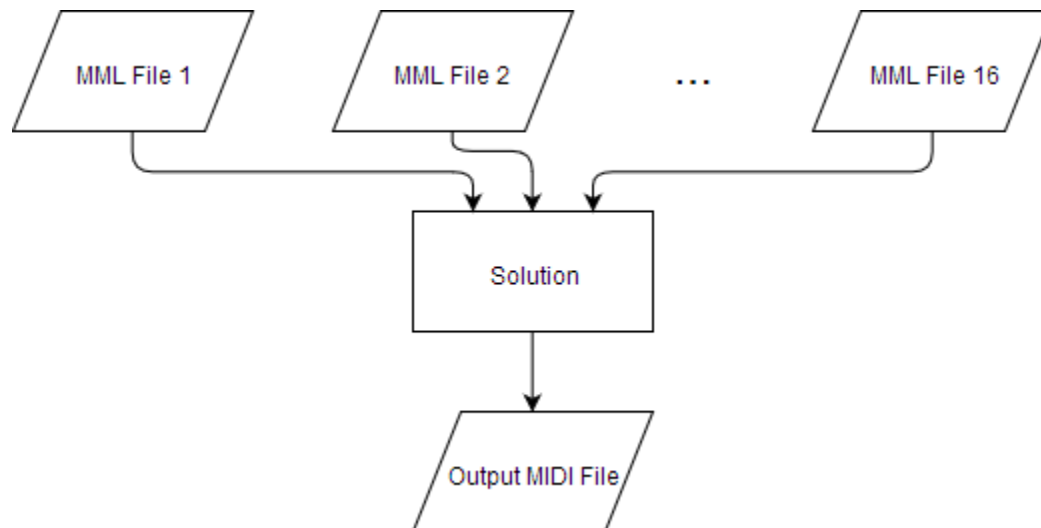
Use Cases

A musician whom uses the MML to compose music would likely find the tools written for this project very useful, as it allows the conversion of their preferred format to an easily playable and portable form.

The solution would also very suitable for a less musically experienced individual, as it is easy to alter and enter music in MML, in contrast to traditional sheet music.

Potential Solutions

One solution to the problem is to have one terminal program that the user enters the paths to the input MML files into, and have it output the desired MIDI file. There are a number of pros and cons in this potential solution:

Single Program Advantages	Single Program Disadvantages
Easy to use	The program would be complex, given what functionality it must have

Another solution would be to have two programs that are designed to be used in conjunction: the first would take a single MML file and output a single-channel MIDI file, and the second would take multiple single-channel MIDI files and output a single multiple-channel MIDI file. Some advantages and disadvantages to this approach are shown in the following table.

Program Pair Advantages	Program Pair Disadvantages
Each program would be more simple to write, compared to a single complex program	More difficult for to use
Each channel of the final MIDI file can be listened to, as a single-channel MIDI file of it would be generated before-hand	

Chosen Solution

I have chosen to use the solution featuring a pair of programs. This is primarily because I feel that the complexity of both programs combined would be less than the complexity of one larger program.

Objectives of the Project

- A program should be written that takes text file containing a variant of the MML as an input, and outputs a single-channel MIDI file that can be play with conventional software.

- A program should be written that takes up to 16 MIDI files generated by the aforementioned program and combines them into a single multi-channel MIDI file. This combined MIDI file should be playable using conventional software also.

- The programs written for this project should:
    - Complete their execution in under one second, so as to not interrupt the users work flow
    - Use less than half a megabyte of memory during execution
    - Be a less than a quarter of a megabyte in size

- A version of the music macro language should be designed that will be used as the input for the program that generates a single-channel MIDI file from a single MML file. This language should:
    - Have all the functionality of existing variants of the MML, including support for:
        - Octave changing
        - Accidentals
        - Default length setting
        - Volume changing
        - Tempo setting
        - Macros

Documented Design

Target Hardware

The programs written for this project will be targeted at Unix based operating systems such as OS X and Linux, as this is what I will be developing them on, and I am used to working with these systems. Also, the programs will be written to run on little endian processors – this is relevant because the endianness of many values will need to be flipped during the generation of the MIDI files.

Overall System Design

The following tables are IPSO charts for the mmltomidi and catmidi programs respectively:

Inputs	Processes	Storage	Outputs
MML text file	MML text	Single-channel MIDI file	Success message

Inputs	Processes	Storage	Outputs
Single-channel MIDI files	MIDI file contents	Multi-channel MIDI file	Success message

mmltomidi – User Interface

The mmltomidi program will be called via the terminal with the form shown below:

mmltomidi [-o output_path] mml_file

The "-o" switch sets the output file to be the "output_path" following. If the switch is not present, then the output file will be called "output.midi" and placed in the working directory. The "mml_file" portion is where the path to the input file is put.

catmidi – User Interface

The catmidi program will be called, similarly to mmltomidi, via the terminal with the form shown below:

catmidi [-o output_path] [path ...]

The "-o" switch will function exactly as described in the mmltomidi user interface section. "[path ...]" is where the paths to the input MIDI files are put, delimited by spaces

mmltomidi – Procedural Abstraction

The following is a flow chart showing a broad abstraction of how the mmltomidi program will work:
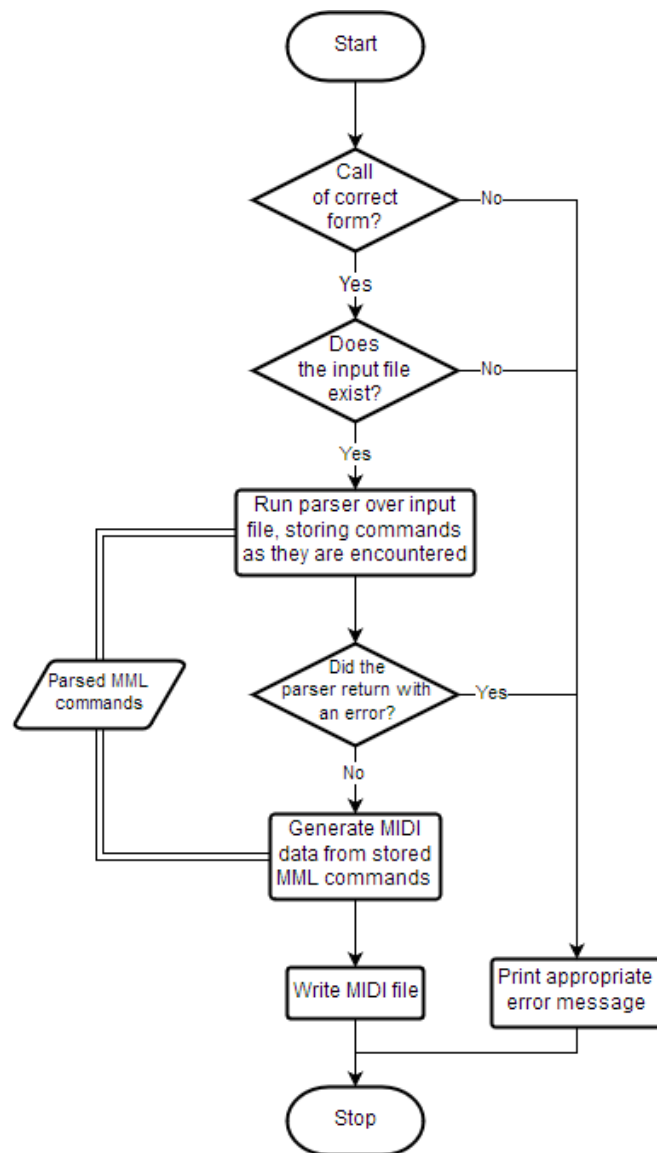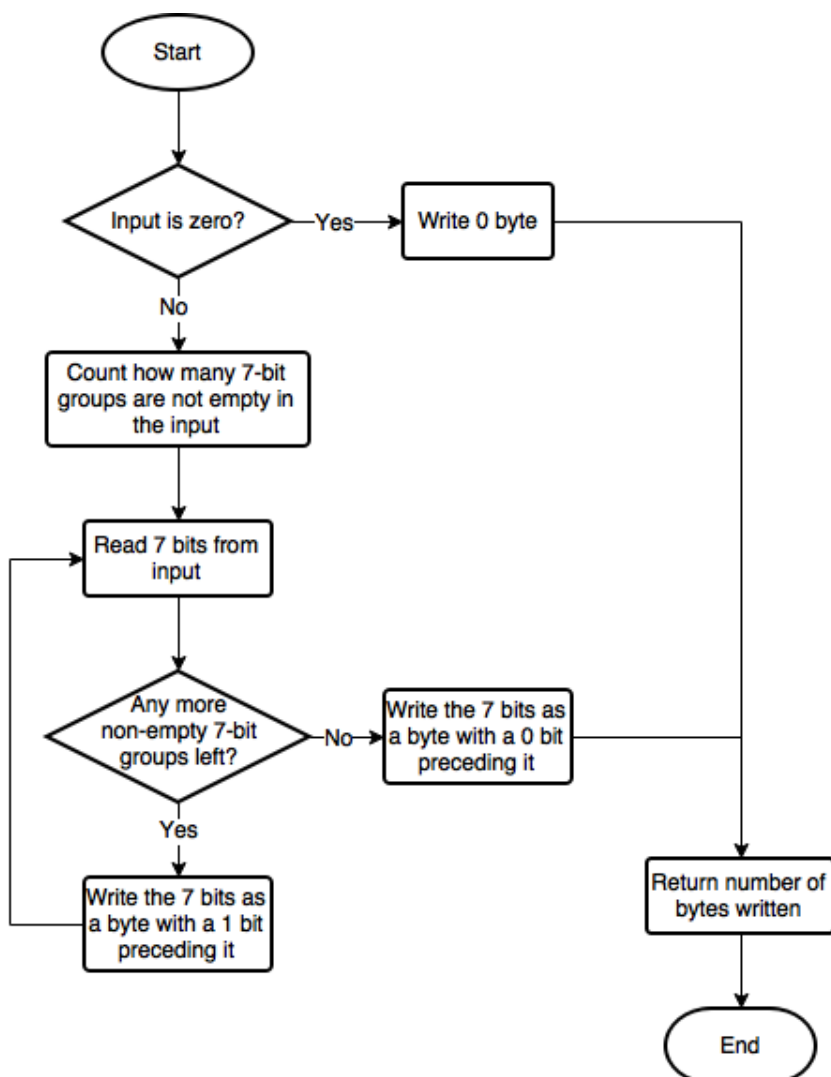
mmltomidi – Key Algorithms

Variable Length Quantity Writing

One of the most utilised algorithms will be to write a variable length quantity. It will take as inputs a pointer to where the data should be written, and the number that should be written as a variable length quantity. It will return the length of the data written. A list of inputs and expected outputs in hexadecimal for this algorithm are shown below.

Input Number	Data Written	Length of Data Written
00 00 00 00	00	1
00 00 00 7F	7F	1
00 00 00 80	81 00	2
00 00 3F FF	FF 7F	2
00 00 40 00	81 80 00	3
0F FF FF FF	FF FF FF 7F	4

A flow chart showing a procedural abstraction of the algorithm is below.

Endianness Swapper

An endianness swapper is another algorithm that will be commonly used throughout the mmltomidi program. It will take a binary number as an input and output the same binary number, but with its endian swapped. The table below shows what outputs would be given for example inputs.

Input Binary Number	Output Binary Number
00 00 00 00	00 00 00 00
00 00 00 FF	FF 00 00 00
00 FF 00 00	00 00 FF 00
12 34 56 78	78 56 34 12

A C-like pseudo-code implementation of this algorithm is shown below.

```
int swapIntEndian(int input) {
    int output = 0;

    for each byte in input {
        write the byte to the byte of opposite significance in output
    }

    return output
}
```

MIDI Data from Processed MML Commands

The key algorithm of the program, however, is that which generates the MIDI data from the processed MML text data. The flowchart below demonstrates how it will function.
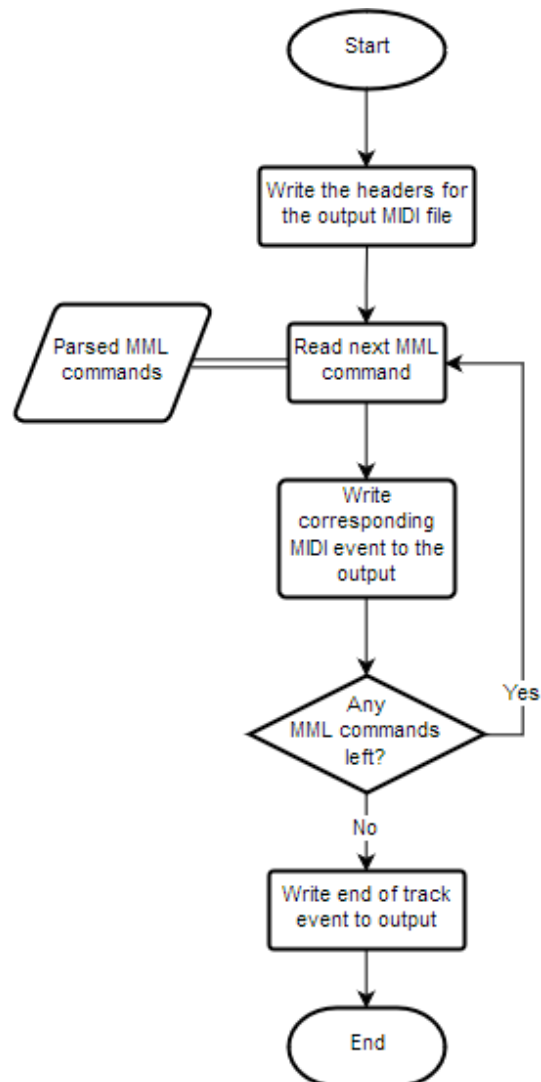
mmltomidi – Main Data Structures

The following chunk of code represents the key data structures that store the MML data found by the parser for the MIDI data-generating program.

```
struct note {
        char command; //Letter
        char accidental; //-1 for flat, 1 for
sharp
        unsigned char modifier; //Number after
};

struct mmlFileStruct {
        char name[256]; //Null terminated

        struct note notes[16384];
        int noteCount;
};
```

The main structure is "mmlFileStruct". This contains the name of the track, the number of notes in the track, and a list of every note and command in the program. The "note" structure is used only to represent a note or command in the "mmlFileStruct" structure. It contains the letter representing the command, whether a note is an accidental or not, and the modifying number for the command.

Below is an example assignment of these data structures.

```
struct mmlFileStruct exampleMMLFileStruct;

strcpy(exampleMMLFileStruct.name, "Test track");
exampleMMLFileStruct.notes[0].command = 'a';
exampleMMLFileStruct.notes[0].accidental = 0;
exampleMMLFileStruct.notes[0].modifier = 5;
exampleMMLFileStruct.noteCount = 1
```

This example data represents a MML file with the name "Test track", which contains a single crochet of note "A".

catmidi – Procedural Abstraction

The following is a flow chart showing a broad abstraction of how the catmidi program will work:
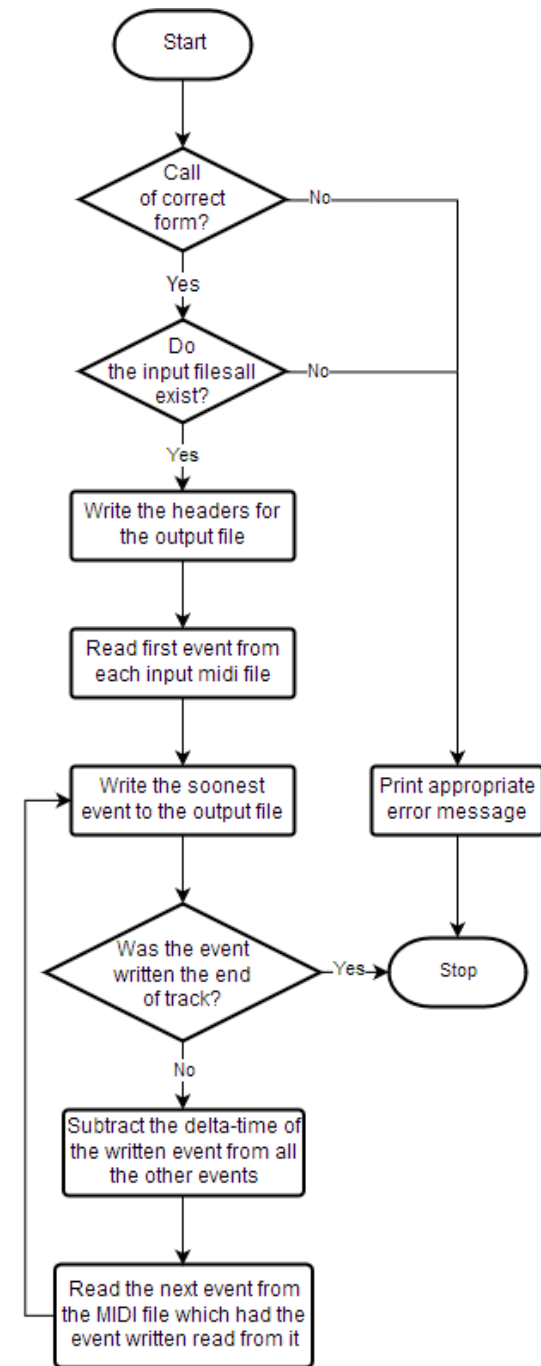
catmidi – Key Algorithms

The catmidi program shares many of the same algorithms as the mmltomidi program, including the variable length quantity writing algorithm and the endianness swapper. In light of this, only algorithms, which aren't featured in the mmltomidi program, are described in the following sections.

Variable Length Quantity Reading

One of the main algorithms used in the catmidi program is one that reads a variable length quantity and returns an integer. This is very similar to the variable length quantity writing algorithm covered before. It will take a pointer to the variable length quantity to be read as an input, and return an integer. The table below shows what outputs would be expected from the given inputs.

Input Data	Number Outputted
00 00 00 00	00
00 00 00 7F	7F
00 00 81 00	80
00 00 FF 7F	3F FF
00 81 80 00	40 00
FF FF FF 7F	0F FF FF FF

An implementation of this algorithm as a C function is shown below.

```
int writeVariableLengthQuantity(char *outputPtr, int input) {
  if (input == 0) {
    *outputPtr = 0;
    return 1;
  }

  int length = 5;

  for (int i = 4; i >= 0; i--) {
    if (input >> i * 7) {
      break;

    } else {
      length--;
    }
  }

  for (int i = length - 1; i >= 0; i--) {
    if (i != 0) {
```

```
            *(outputPtr + length - i - 1) = ((input >> i * 7) & 0x7F) + 0x80;

        } else {
            *(outputPtr + length - i - 1) = (input >> i * 7) & 0x7F;
        }
    }


    return length;
}
```

Read MIDI Event

A core algorithm used is that which reads an event from an input MIDI file and outputs a structure containing the event and its delta time, with the channel number replaced where appropriate. It will take a pointer to the buffer where the MIDI data is stored, a pointer to a event structure, which is where the event will be stored, and a channel number. The algorithm is broadly demonstrated below in pseudo-code.

```
void readMTrkEvent(unsigned char *inputPtr, struct mtrkEvent *outputPtr, char
channelNumber) {
        outputPtr->deltaTime = readVariableLengthQuantity(inputPtr);

        Copy event to outputPtr->event

        Replace channel number in applicable events

        outputPtr->length = length of event stored
}
```

Combine MIDI Files

The main algorithm of the catmidi program is that which actually combines the MIDI files. It will take a pointer to an output buffer and pointers to MIDI files that have been read into memory. The pseudo-code for this algorithm is shown below.

```
int combineMIDIFiles(char *outputBuffer, unsigned char *inputBuffer[]) {
        Write output chunk headers

        Move the input buffer pointers to the start of events

        Read an event from each MIDI file and store them

        while (1) {
                Write the event with the smallest delta time to the output

                If this was the end of track MIDI event {
                        return length of written MIDI file;
                }

                Subtract delta time of event written from all other event delta times

                Read the next event from the input buffer the event was written from
        }
}
```

catmidi – Main Data Structures

The only data structure in use in the catmidi program is that which stores the read MIDI events. It is shown below as a C structure.

```
struct mtrkEvent {
        char event[262];
        short length;
        int deltaTime;
};
```

The event itself is stored in "event", which is sized such that no recognised command will exceed its capacity. The length of the event is stored in "length". Finally, the delta time of the MIDI event (that is, the time between carrying out the following command and the previous one), is stored in the "deltaTime" integer. In the MIDI file itself this is stored as a variable length quantity.

An example assignment of this structure is shown below, containing an end of track event.

```
struct mtrkEvent exampleEvent;

memcpy(exampleEvent.event, (char []) {0xFF, 0x2F, 0x00}, 3);
exampleEvent.length = 3;
exampleEvent.deltaTime = 0;
```

Music Macro Language Design

This section describes the music macro language used by the mmltomidi program.

Introduction

The music macro language (MML) is a music description language that has been in use since 1978, although this was an early version. There has never been an official specification, so each implementation varies slightly, and over the years the language has evolved. The MML to MIDI converter uses a version of the MML derived largely from "Classical MML" with some "Modern MML" features present. Some new specific commands are included also, and some commands are changed where necessary.

All commands in this language have their own line and are terminated by a new line ("\n", "\r "or "\r\n").

Comments

Comments are started with two hash characters at the beginning of a new line. This makes the remainder of the line a comment; any more hashes found on the line have no effect. Two hashes are used because single hash starts a meta command.

Playing Notes

The "play" command is used to play a series of notes and macros. Spaces can be intermingled with the notes to improve the clarity of the code. An example usage of this command is shown below:

play c5e5g5

Note Syntax

Notes are written as the note name followed optionally by the length of the note as a digit – each value for this digit represents a musical note length, which can be seen in the table below. If a length is not given, the default value is used, which is initially 5, but can be changed with the "l" command detailed shortly. A rest is represented by the note name "r". To play an accidental note a "+" or "-", respectively, is added after the note name and before the note length. Accidentals applied to rests are ignored.

MML Note Value Number	Musical Note	
	American Notation	Name
0	1/32	Demisemiquaver
1	1/16	Semiquaver
2	1/16 + 1/32	Dotted semiquaver
3	1/8	Quaver
4	1/8 + 1/16	Dotted quaver
5	1/4	Crochet
6	1/4 + 1/8	Dotted crochet
7	1/2	Minim
8	1/2 + 1/4	Dotted minim
9	1	Semibreve

To alter how each note is played, there are some of commands entered with the notes. These are listed below (where square brackets and their contents are not literal):

- o[digit]   Set the octave each following note is played in. The digit represents the scientific pitch notation (SPN) number of the desired octave. All notes entered before this command is entered are played in the 4th SPN octave ("A" will be 440 Hz.)

- <   Shift the octave down by one.

- > Shift the octave up by one.

- v[digit]   Set the volume of the following notes. By default, notes will play at 100% volume.

- p[number from 0 to 11]   Transpose all the following notes up by the number following 'p' semitones. The default setting is 0.

- l[digit] Set the default length of the following notes to the digit. The initial default length is 5. Note that this does not affect the 'v' or 'o' commands.

In modern MML there is also a "t" command, which sets the tempo. This is not included, as a more obvious command on its own line is favoured for ease of reading.

Meta Commands

These commands are entered on their own lines only once and are all preceded by a single hash. They tell the converter how the rest of the file should be played and add information to the MIDI file.

- #tempo [BPM] – set the tempo in BPM of the track (where a beat is a crochet.) This should be set the same in each MML track file when combining them into one MIDI file. The default tempo is 120 BPM.

- #instrument [general MIDI patch number] – set the instrument the rest of the file should be played with. The default instrument is a piano (GM patch number 0.) This command is not present in other MML versions because it is only useful if the file is being converted to a MIDI file.

- #name [name] – set the name of the track. This is put verbatim into the MIDI file in a track name meta event, and can be very useful when altering the MIDI file directly. Only one instance of this command should be in a MML file, otherwise a syntax error will occur.

Macros

A macro in this version of MML is written as below (on its own line):

$c v9o4c5

The dollar sign shows that this is a macro definition, and the letter following this is the "name" of the macro. The text after the dollar sign and letter replaces any other instance of

the macro name found. A limitation of this notation is that there are only 26 possible macro names, but it is done this way to be more compatible with other versions of MML. Macros can be defined more than once.

Full Example

To conclude this section, a short example of an MML file is shown below.

```
##Example comment

#name test_track
#instrument 0
#tempo 120

$c cdefgab>c

play v8r9$cr9
```

The MIDI file that would be generated from this example is shown below, split into rows in a table with explanations.

MIDI Data		Description
4D 54 68 64 00 00 00 06 00 00 00 01 00 08		Header chunk
4D 54 72 6B 00 00 00 7E		Track chunk header
00 FF 03 0A 74 65 73 74 5F 74 72 61 63 6B		Track name assignment
00 FF 58 04 04 02 18 08		Time signature assignment
00 FF 51 03 03 D0 90		Tempo setting (This is the default tempo)
00 C0 00		Patch change (This is the default instrument)
00 C0 00		Patch change (This is the instrument specified in the MML file)
00 FF 51 03 03 D0 90		Tempo setting (This is the tempo specified in the MML file)
00 90 00 00	00 90 43 70	This is a string of note on and note off MIDI events that correspond to the notes described in the MML file
20 80 00 00	08 80 43 70	
00 90 3C 70	00 90 45 70	
08 80 3C 70	08 80 45 70	
00 90 3E 70	00 90 47 70	
08 80 3E 70	08 80 47 70	
00 90 40 70	00 90 48 70	
08 80 40 70	08 80 48 70	
00 90 41 70	00 90 00 00	
08 80 41 70	20 80 00 00	
00 FF 2F 00		End of track event

Finally, below is the sheet music equivalent of the MML example file.

MML in Regex and BNF

This section shows how I will encode the language described in the previous section using regular expressions and Backus-Naur form. These expressions can be put verbatim into the Lex and Yacc input files. The figure below contains the BNF grammar for the MML. "<mmlFile>" is the start symbol.

```
<mmlFile> ::= <line> | <mmlFile> <line>

<line> ::= <LINE_BREAK> |
        <COMMENT> |
        <TEMPO_SET> |
        <INSTRUMENT_SET> |
        <NAME_SET> |
        <MACRO_ASSIGNED> |
        <PLAY_COMMAND>
```

The following table shows what regexes correspond to what BNF symbol, and gives a description for them.

Regex	BNF Symbol	Description
^##.*(\r|\n|(\r\n))	COMMENT	Matches comment lines.
^(\r|\n|(\r\n))	LINE_BREAK	Matches an empty line.
^#tempo" "[0-9]{1,3}(\r|\n|(\r\n))	TEMPO_SET	Matches a tempo setting line.
^#instrument" "[0-9]+(\r|\n|(\r\n))	INSTRUMENT_SET	Matches an instrument assigning line.
^#name" "[a-zA-Z0-9_]+(\r|\n|(\r\n))	NAME_SET	Matches a name setting line.
^$[a-z]" "(([cdefgabrov][+-]?[0-9]?)|($[a-z])|[<>]|(p[0-9]+)|(l[0-9])|" ")+(\r|\n|(\r\n))	MACRO_ASSIGNED	Matches a macro assignment. The middle portion is the regex that matches series of notes.
^play" "(([cdefgabrov][+-]?[0-9]?)|($[a-z])|[<>]|(p[0-9]{1,2})|(l[0-9])|" ")+(\r|\n|(\r\n))	PLAY_COMMAND	Matches a play command. The middle portion is, again, the regex that matches a series of notes.

Technical Solution

---

mmltomidi/makefile

```makefile
BUILD_DIR = ./build
STD = -std=c99
OPTI = -O3
EXE = mmltomidi

$(EXE): main.c main.h y.tab.c lex.yy.c
  gcc -g -w $(STD) $(OPTI) -o $(BUILD_DIR)/$(EXE) main.c $(BUILD_DIR)/lex.yy.c
$(BUILD_DIR)/y.tab.c

lex.yy.c: lex.l y.tab.h
  lex -s -o $(BUILD_DIR)/lex.yy.c lex.l

y.tab.c y.tab.h: yacc.y
  yacc -d -o $(BUILD_DIR)/y.tab.c yacc.y

.PHONY: clean

clean:
  rm -f $(BUILD_DIR)/$(EXE)
  rm -f $(BUILD_DIR)/*.o
  rm -f $(BUILD_DIR)/*.c
  rm -f $(BUILD_DIR)/*.h
```

---

mmltomidi/main.c

```c
#include <stdio.h>
#include <string.h>
#include <stdbool.h>
#include <unistd.h>

#include "main.h"
#include "mmlFileStruct.h"

struct mmlFileStruct processedMmlFile; //Necessary global for info from lex.yy
extern FILE *yyin; //For linking to lex.yy.c
extern bool macroEnabled[26]; //Necessary for clearing

int swapIntEndianness(int input) {
  //Swaps integer endianness

  int output = 0;

  for (int i = 0; i < 4; i++) {
    *((char *) &output - i + 3) = *((char *) &input + i);
  }

  return output;
}

int swapShortEndianness(short input) {
  //Swaps short endianness

  int output = 0;

  for (int i = 0; i < 2; i++) {
    *((char *) &output - i + 1) = *((char *) &input + i);
  }

  return output;
}

int writeVariableLengthQuantity(char *outputPtr, int input) {
  //Writes "input" as a variable length quantity at where "outputPtr" points to.
  //Returns length of variable length quantity written

  if (input == 0) {
    *outputPtr = 0;
    return 1;
```

```c
  }

  int length = 5;

  for (int i = 4; i >= 0; i--) {
    if (input >> i * 7) {
      break;

    } else {
      length--;
    }
  }

  for (int i = length - 1; i >= 0; i--) {
    if (i != 0) {
      *(outputPtr + length - i - 1) = ((input >> i * 7) & 0x7F) + 0x80;

    } else {
      *(outputPtr + length - i - 1) = (input >> i * 7) & 0x7F;
    }
  }

  return length;
}

void writeMTrkHeader(struct mtrkHeader *mtrkHeaderPtr, int trackLength) {
  //Fills in a given mtrkHeader struct

  strncpy(mtrkHeaderPtr->chunkType, "MTrk", 4);
  mtrkHeaderPtr->length = swapIntEndianness(trackLength);
}

void writeMThdHeader(struct mthdHeader *mthdHeaderPtr) {
  //Fills in a given mthdHeader struct

  strncpy(mthdHeaderPtr->chunkType, "MThd", 4);
  mthdHeaderPtr->length = swapIntEndianness(6);
  mthdHeaderPtr->format = 0;
  mthdHeaderPtr->ntrks = swapShortEndianness(1);
  mthdHeaderPtr->division = swapShortEndianness(8);
}

int generateMIDIFile(char **outputPtr, struct mmlFileStruct *midiData) {
  //Points outputPtr towards a malloc assigned array containing the MIDI
  //file described by midiData

  *outputPtr = malloc(65536);

  if (*outputPtr == NULL) {
    fprintf(stderr, "Error - memory could not be assigned by malloc\n");
    return NULL;
  }

  struct mthdHeader *outputMThdHeader = *outputPtr;
  struct mtrkHeader *outputMTrkHeader = *outputPtr + 14;
  char *trackChunkPtr = *outputPtr + 22;

  writeMThdHeader(outputMThdHeader);

  if (midiData->name[0]) {
    memcpy(trackChunkPtr, (char []) {0x00, 0xff, 0x03, strlen(midiData->name)}, 4);
    strcpy(trackChunkPtr += 4, midiData->name);
    trackChunkPtr += strlen(midiData->name);
  }

  //Default time signature
  memcpy(trackChunkPtr, (char []) {0x00, 0xFF, 0x58, 0x04, 0x04, 0x02, 0x18, 0x08},
8);
  trackChunkPtr += 8;

  //Default tempo
  memcpy(trackChunkPtr, (char []) {0x00, 0xFF, 0x51, 0x03}, 4);
  *((int *) (trackChunkPtr += 4)) = swapIntEndianness(30000000 / 120) >> 8;
  trackChunkPtr += 3;

  //Default instrument
  memcpy(trackChunkPtr, (char []) {0x00, 0xC0, 0x00}, 3);
```

```c
  trackChunkPtr += 3;

char octave = 4;
char velocity = 0x7F;
char transposition = 0;
char noteLookup[7] = {21, 23, 12, 14, 16, 17, 19};
char deltaTimeLookup[10] = {1, 2, 3, 4, 6, 8, 12, 16, 24, 32};

for (int i = 0; i < midiData->noteCount; i++) {
  struct note currentNote = midiData->notes[i];

  switch (currentNote.command) {
    case 'o':
      octave = currentNote.modifier;
      break;

    case '<':
      octave -= octave != 0;
      break;

    case '>':
      octave += octave != 9;
      break;

    case 'p':
      transposition = currentNote.modifier;
      break;

    case 'v':
      velocity = (0x7F * currentNote.modifier) / 9;
      break;

    case 't':
      memcpy(trackChunkPtr, (char []) {0x00, 0xFF, 0x51, 0x03}, 4);
      *((int *) (trackChunkPtr += 4)) = swapIntEndianness(30000000 /
currentNote.modifier) >> 8;
      trackChunkPtr += 3;

      break;

    case 'i':
      memcpy(trackChunkPtr, (char []) {0x00, 0xC0, currentNote.modifier}, 3);
      trackChunkPtr += 3;

      break;

    default:
      ; //Should always be a note

      char noteNumber = noteLookup[currentNote.command - 'a'] + 12 * octave +
currentNote.accidental + transposition;

      memcpy(trackChunkPtr, (char []) {0x00, 0x90, (currentNote.command != 'r') *
noteNumber, (currentNote.command != 'r') * velocity}, 4);
      trackChunkPtr += 4;

      trackChunkPtr += writeVariableLengthQuantity(trackChunkPtr,
deltaTimeLookup[currentNote.modifier]);
      memcpy(trackChunkPtr, (char []) {0x80, (currentNote.command != 'r') *
noteNumber, (currentNote.command != 'r') * velocity}, 3);
      trackChunkPtr += 3;

      break;
  }
}

//End of track message
memcpy(trackChunkPtr, (char []) {0x00, 0xFF, 0x2F, 0x00}, 4);
trackChunkPtr += 4;

writeMTrkHeader(outputMTrkHeader, trackChunkPtr - *outputPtr - 22);

*outputPtr = realloc(*outputPtr, trackChunkPtr - *outputPtr + 1);

if (*outputPtr == NULL) {
  fprintf(stderr, "Error - malloc'd array could not be reallocated\n");
```

```c
    return NULL;
  }

  return trackChunkPtr - *outputPtr;
}

bool fileReadable(char *path) {
  //Checks if the program has the rights to read the input file

  if (access(path, R_OK)) {
    fprintf(stderr, "File %s is not readable\n", path);
    return false;
  }

  return true;
}

bool pathValid(char *path) {
  //Checks if the input path leads to something
  //Currently does not error on a directory

  if (access(path, F_OK)) {
    fprintf(stderr, "File %s does not exist\n", path);
    return false;
  }

  return true;
}

bool correctCallForm(int argc, char *argv[]) {
  //Returns a boolean for if the call is of the right form

  if ((argc != 2) && (argc != 4)) {
    fprintf(stderr, "Invalid number of arguments given\n");

    return false;
  }

  return true;
}

int main(int argc, char *argv[]) {
  if (!correctCallForm(argc, argv)) {
    fprintf(stderr, "Usage: mmltomidi [-o output_path] file\n");

    return 1;
  }

  bool outputPathGiven = (strcmp(argv[1], "-o")) ? false : true;
  char *outputPath = (outputPathGiven) ? argv[2] : "output.midi";
  char *inputPath = (outputPathGiven) ? argv[3] : argv[1];

  if ((!pathValid(inputPath)) || (!fileReadable(inputPath))) {
    return 1;
  }

  memset(&processedMmlFile, 0, sizeof(processedMmlFile));
  memset(macroEnabled, 0, 26);

  yyin = fopen(inputPath, "rb");
  int yyparseResult = yyparse();
  fclose(yyin);

  if (yyparseResult == 1) {
    fprintf(stderr, "Syntax error encountered by parser - terminating\n");

    return 1;
  }

  char *midiBuffer;
  int midiBufferLength = generateMIDIFile(&midiBuffer, &processedMmlFile);

  if (midiBuffer == NULL) {
    return 1;
  }

  FILE *outputFile = fopen(outputPath, "wb");
```

```c
    if (outputFile == NULL) {
        fprintf(stderr, "Output file could not be created/opened\n");

        return 1;
    }

    fwrite(midiBuffer, 1, midiBufferLength, outputFile);

    free(midiBuffer);
    fclose(outputFile);

    return 0;
}
```

mmltomidi/main.h

```c
#ifndef MAIN_H
#define MAIN_H

extern int yyparse (void); //Function prototype for linking to y.tab.c

struct mthdHeader {
    char chunkType[4];
    int length;
    short format;
    short ntrks;
    short division;
};

struct mtrkHeader {
    char chunkType[4];
    int length;
};

#endif
```

mmltomidi/lex.l

```c
%{
#include <stdlib.h>
#include <string.h>
#include <stdbool.h>

#include "y.tab.h"
#include "../mmlFileStruct.h"

extern struct mmlFileStruct processedMmlFile;

char macroTable[26][256]; //Null terminated
bool macroEnabled[26];

void replaceSubstring(char *source, char *find, char *replace) {
    //Replaces the substring "find" with "replace" in "source"
    //Requires source to point to a malloc assigned array

    int matches = 0;
    char *i = strstr(source, find);

    while (i != NULL) {
        matches++;
        i = strstr(i + 1, find);
    }

    if (!matches) {
        return;
    }

    char originalSource[strlen(source)];
    strcpy(originalSource, source);

    source = realloc(source, strlen(source) - matches * strlen(find) + matches *
```

```
    strlen(replace));

  int sourceLen = strlen(source) - matches * strlen(find) + matches *
strlen(replace);

  if (source == NULL) {
    return;
  }

  int oldIndex = 0, newIndex = 0;
  char *nextMatch = NULL;

  while (oldIndex != strlen(originalSource)) {
    if (nextMatch == NULL) {
      nextMatch = strstr(originalSource + oldIndex, find);

      if (nextMatch == NULL) {
        strcpy(source + newIndex, originalSource + oldIndex);
        break;
      }
    }

    if (nextMatch == originalSource + oldIndex) {
      strcpy(source + newIndex, replace);
      newIndex += strlen(replace);
      oldIndex += strlen(find);
      nextMatch = NULL;

    } else {
      source[newIndex++] = originalSource[oldIndex++];
    }
  }
}

%}

%%
^##.*(\r|\n|(\r\n)) {
  return COMMENT;
  }

^(\r|\n|(\r\n)) {
  return LINE_BREAK;
  }

^#tempo" "[0-9]{1,3}(\r|\n|(\r\n)) {
  int tempoNumber = atoi(yytext + 7);

  if (tempoNumber > 255) {
    strcpy(yylval.errorMessage, "Error - tempo set higher than 255");
    return ERROR;
  }

  struct note *currentNote = processedMmlFile.notes + processedMmlFile.noteCount;
  currentNote->command = 't';
  currentNote->modifier = tempoNumber;
  processedMmlFile.noteCount++;

  return TEMPO_SET;
  }

^#instrument" "[0-9]+(\r|\n|(\r\n)) {
  int instrumentNumber = atoi(yytext + 11);

  if (instrumentNumber > 127) {
    strcpy(yylval.errorMessage, "Error - instrument set higher than 127");
    return ERROR;
  }

  struct note *currentNote = processedMmlFile.notes + processedMmlFile.noteCount;
  currentNote->command = 'i';
  currentNote->modifier = instrumentNumber;
  processedMmlFile.noteCount++;

  return INSTRUMENT_SET;
  }
```

```
^#name" "[a-zA-Z0-9_]+(\r|\n|(\r\n)) {
  static bool nameSet = false;

  if (nameSet) {
    strcpy(yylval.errorMessage, "Error - name set more than once");
    return ERROR;
  }

  nameSet = true;
  int i = 5;

  while (yytext[i] != '\n' && yytext[i] != '\r') {
    if (i == 261) {
      strcpy(yylval.errorMessage, "Error - name set was too long: limit is 255");
      return ERROR;
    }

    processedMmlFile.name[i - 6] = yytext[i++];
  }

  processedMmlFile.name[i - 6] = '\0';

  return NAME_SET;
}

^$[a-z]" "(([cdefgabrov][+-]?[0-9]?)|($[a-z])|[<>]|(p[0-9]+)|(l[0-9]))|"
")+(\r|\n|(\r\n)) {
  int i = 3;

  while (yytext[i] != '\n' && yytext[i] != '\r') {
    if (i == 258) {
      strcpy(yylval.errorMessage, "Macro assigned was too long - limit is 255");
      return ERROR;
    }

    macroTable[yytext[1] - 'a'][i - 3] = yytext[i++];
  }

  macroEnabled[yytext[1] - 'a'] = true;
  macroTable[yytext[1] - 'a'][i - 3] = '\0';

  return MACRO_ASSIGNED;
}

^play" "(([cdefgabrov][+-]?[0-9]?)|($[a-z])|[<>]|(p[0-9]{1,2})|(l[0-9]))|"
")+(\r|\n|(\r\n)) {
  char *processedYYText = malloc(strlen(yytext)); //Malloc required for
replaceSubstring

  if (processedYYText == NULL) {
    strcpy(yylval.errorMessage, "Error - memory could not be malloc'd");
    return ERROR;
  }

  strcpy(processedYYText, yytext);

  for (int i = 0; i < strlen(yytext); i++) {
    if ((yytext[i] == '$') && (!macroEnabled[yytext[i + 1] - 'a'])) {
      strcpy(yylval.errorMessage, "Macro used but not assigned");
      return ERROR;
    }
  }

  for (char i = 0; i < 26; i++) {
    if (macroEnabled[i]) {
      replaceSubstring(processedYYText, (char []) {'$', i + 'a', 0x00},
macroTable[i]);

      if (processedYYText == NULL) {
        strcpy(yylval.errorMessage, "Error - memory assigned by malloc could not be
reallocated");
        return ERROR;
      }
    }
  }

  int index = 5;
```

```
    char defaultLength = 5;
    struct note *currentNote;

  while (index < strlen(processedYYText)) {
    currentNote = processedMmlFile.notes + processedMmlFile.noteCount;

    if (strchr("cdefgabrov", processedYYText[index]) != NULL) {
      currentNote->command = processedYYText[index++];
      currentNote->accidental = 0;
      currentNote->modifier = defaultLength;

      while (1) {
        if ((index < strlen(processedYYText)) && (strchr("+-",
processedYYText[index]) != NULL)) {
          currentNote->accidental = (processedYYText[index++] == '+') ? 1 : -1;

          continue;
        }

        if ((index < strlen(processedYYText)) && (strchr("0123456789",
processedYYText[index]) != NULL)) {
          currentNote->modifier = processedYYText[index++] - '0';

          continue;
        }

        break;
      }

      processedMmlFile.noteCount++;

    } else if (strchr("<>", processedYYText[index]) != NULL) {
      currentNote->command = processedYYText[index++];
      processedMmlFile.noteCount++;

    } else if (processedYYText[index] == 'p') {
      currentNote->command = processedYYText[index++];
      currentNote->modifier = 0;

      if ((index + 1 < strlen(processedYYText)) && (strchr("0123456789",
processedYYText[index + 1]) != NULL)) {
        currentNote->modifier = (processedYYText[index++] - '0') * 10;
      }

      currentNote->modifier += processedYYText[index++] - '0';

      if (currentNote->modifier > 11) {
        strcpy(yylval.errorMessage, "Transposition set too high - only values from
0 to 11 are valid");
        return ERROR;
      }

      processedMmlFile.noteCount++;

    } else if (processedYYText[index] == 'l') {
      defaultLength = processedYYText[++index] - '0';
      index++;

    } else {
      //Should never occur, as such an input should not get past the regex
      index++;
    }
  }

  free(processedYYText);

  return PLAY_COMMAND;
}

.|\n|\r {
  return ERROR;
  }
%%
```

mmltomidi/mmlFileStruct.h

```c
#ifndef MMLFILESTRUCT_H
#define MMLFILESTRUCT_H

//Necessary for only one copy of the struct definition to exist

struct note {
  char command;
  char accidental; //-1 for flat, 1 for sharp
  unsigned char modifier;
};

struct mmlFileStruct {
  char name[256]; //Null terminated

  struct note notes[16384];
  int noteCount;
};

#endif
```

mmltomidi/yacc.y

```c
%{
#include <stdio.h>
#include <stdbool.h>

void yyerror(char *s) {
  fprintf(stderr, "%s\n", s);
}

int yywrap() {
  return 1;
}

%}

%union {
  int value;
  char errorMessage[256];
}

%start mmlFile

%token <value> COMMENT
%token <value> LINE_BREAK
%token <value> TEMPO_SET
%token <value> INSTRUMENT_SET
%token <value> NAME_SET
%token <value> MACRO_ASSIGNED
%token <value> PLAY_COMMAND
%token <errorMessage> ERROR

%type <value> line

%%
mmlFile:  line
    |  mmlFile line
    ;

line:  LINE_BREAK
    |  COMMENT
    |  TEMPO_SET
    |  INSTRUMENT_SET
    |  NAME_SET
    |  MACRO_ASSIGNED
    |  PLAY_COMMAND
    |  ERROR {
      fprintf(stderr, "%s\n", $1);
      YYERROR;
    };
%%
```

catmidi/main.c

```c
#include <stdio.h>
#include <stdlib.h>
#include <stdbool.h>
#include <unistd.h>
#include <string.h>

#include "main.h"

int readVariableLengthQuantity(char *inputPtr) {
  //Reads a varible length quantity from "inputPtr" and returns it as an integer

  char *workingPtr = inputPtr;

  while (*workingPtr & 0x80) {
    workingPtr++;
  }

  int output = 0;
  int outputShift = 0;

  do {
    output |= (*workingPtr & 0x7F) << outputShift;

    outputShift += 7;

  } while (workingPtr-- != inputPtr);

  return output;
}

int writeVariableLengthQuantity(char *outputPtr, int input) {
  //Writes "input" as a variable length quantity at where "outputPtr" points to.
  //Returns length of variable length quantity written

  if (input == 0) {
    *outputPtr = 0;
    return 1;
  }

  int length = 5;

  for (int i = 4; i >= 0; i--) {
    if (input >> i * 7) {
      break;

    } else {
      length--;
    }
  }

  for (int i = length - 1; i >= 0; i--) {
    if (i != 0) {
      *(outputPtr + length - i - 1) = ((input >> i * 7) & 0x7F) + 0x80;

    } else {
      *(outputPtr + length - i - 1) = (input >> i * 7) & 0x7F;
    }
  }

  return length;
}

char readMTrkEvent(unsigned char **inputPP, struct mtrkEvent *outputPtr, char
channelNumber) {
  //Reads a MIDI track event from the double pointer "inputPP"
  //Increases the pointer as the file is read through
  //Stores results in "outputPtr"
  //Returns non-zero on error

  outputPtr->deltaTime = readVariableLengthQuantity((char *) *inputPP);

  while (**inputPP & 0x80) {
    (*inputPP)++;
```

```c
    }

  (*inputPP)++;

  unsigned char *originalPtr = *inputPP;

  switch (**inputPP) {
    case 0xFF:
      (*inputPP)++;

      switch (**inputPP) {
        case 0x03: //Name
          (*inputPP)++;
          *inputPP += **inputPP + 1;

          break;

        case 0x2f: //End
          *inputPP += 2;

          break;

        case 0x51: //Tempo
          *inputPP += 5;

          break;

        case 0x58: //Time sig.
          *inputPP += 6;

          break;

        default:
          fprintf(stderr, "Unknown MTrk event encountered\n");

          return 1;
      }

      break;

    case 0x80: //Note off
    case 0x90: //Note on
      **inputPP |= channelNumber;
      *inputPP += 3;

      break;

    case 0xC0: //Patch change
      **inputPP |= channelNumber;
      *inputPP += 2;

      break;

    default:
      fprintf(stderr, "Unknown MTrk event encountered\n");

      return 1;
  }

  outputPtr->length = *inputPP - originalPtr;
  memcpy(outputPtr->event, originalPtr, outputPtr->length);

  return 0;
}

int swapIntEndianness(int input) {
  //Swaps integer endianness

  int output = 0;

  for (int i = 0; i < sizeof(int); i++) {
    *((char *) &output + sizeof(int) - i - 1) = *((char *) &input + i);
  }

  return output;
}
```

```c
int swapShortEndianness(short input) {
  //Swaps short endianness

  int output = 0;

  for (int i = 0; i < sizeof(short); i++) {
    *((char *) &output + sizeof(short) - i - 1) = *((char *) &input + i);
  }

  return output;
}

void writeMTrkHeader(struct mtrkHeader *mtrkHeaderPtr, int trackLength) {
  //Fills in a given mtrkHeader struct

  strncpy(mtrkHeaderPtr->chunkType, "MTrk", 4);
  mtrkHeaderPtr->length = swapIntEndianness(trackLength);
}

void writeMThdHeader(struct mthdHeader *mthdHeaderPtr) {
  //Fills in a given mthdHeader struct

  strncpy(mthdHeaderPtr->chunkType, "MThd", 4);
  mthdHeaderPtr->length = swapIntEndianness(6);
  mthdHeaderPtr->format = 0;
  mthdHeaderPtr->ntrks = swapShortEndianness(1);
  mthdHeaderPtr->division = swapShortEndianness(8);
}

int combineMIDIFiles(char *outputBuffer, unsigned char *inputBuffer[], char
inputBufferCount) {
  //Combines raw MIDI files passed with the "inputBuffer" array
  //Outputs the combined file to "outputBuffer"
  //Returns zero on error

  struct mthdHeader *outputMThdHeader = (void *) outputBuffer;
  struct mtrkHeader *outputMTrkHeader = (void *) outputBuffer + 14;
  char *trackPtr = (void *) outputBuffer + 22;

  writeMThdHeader(outputMThdHeader);

  unsigned char *inputBufferPtr[inputBufferCount];
  struct mtrkEvent inputEvent[inputBufferCount];

  for (int i = 0; i < inputBufferCount; i++) {
    inputBufferPtr[i] = inputBuffer[i] + 22;

    if (readMTrkEvent(&inputBufferPtr[i], &inputEvent[i], i)) {
      return 0;
    }
  }

  bool nameSet = false;
  bool timeSignatureSet = false;

  int smallestDeltaTime;
  char soonestEventIndex;
  struct mtrkEvent *soonestEvent;

  while (1) {
    smallestDeltaTime = inputEvent[0].deltaTime;
    soonestEventIndex = 0;

    for (int i = 1; i < inputBufferCount; i++) {
      if (inputEvent[i].deltaTime < smallestDeltaTime) {
        smallestDeltaTime = inputEvent[i].deltaTime;
        soonestEventIndex = i;
      }
    }

    for (int i = 0; i < inputBufferCount; i++) {
      if (i == soonestEventIndex) {
        continue;
      }

      inputEvent[i].deltaTime -= smallestDeltaTime;
    }
```

```c
    soonestEvent = &inputEvent[soonestEventIndex];

    if (!memcmp(soonestEvent->event, (char []) {0xFF, 0x03}, 2)) { //Name setting
event
        if (nameSet) {
            if (readMTrkEvent(&inputBufferPtr[soonestEventIndex],
&inputEvent[soonestEventIndex], soonestEventIndex)) {
                return 0;
            }

            continue;
        }

        nameSet = true;
    }

    if (!memcmp(soonestEvent->event, (char []) {0xFF, 0x58, 0x04}, 3)) { //Time
signature setting event
        if (timeSignatureSet) {
            if (readMTrkEvent(&inputBufferPtr[soonestEventIndex],
&inputEvent[soonestEventIndex], soonestEventIndex)) {
                return 0;
            }

            continue;
        }

        timeSignatureSet = true;
    }

    trackPtr += writeVariableLengthQuantity(trackPtr, soonestEvent->deltaTime);
    memcpy(trackPtr, soonestEvent->event, soonestEvent->length);
    trackPtr += soonestEvent->length;

    if (memcmp(soonestEvent->event, (char []) {0xFF, 0x2F, 0x00}, 3) == 0) { //End
of track event
        break;
    }

    if (readMTrkEvent(&inputBufferPtr[soonestEventIndex],
&inputEvent[soonestEventIndex], soonestEventIndex)) {
        return 0;
    }
  }

  writeMTrkHeader(outputMTrkHeader, trackPtr - outputBuffer - 22);

  return trackPtr - outputBuffer;
}

int loadFile(char *path, unsigned char **buffer) {
  //Loads a file stored at "path"

  FILE *f = fopen(path, "rb");

  fseek(f, 0, SEEK_END);
  int length = ftell(f);
  rewind(f);

  *buffer = malloc(length);
  fread(*buffer, 1, length, f);

  fclose(f);

  return length;
}

bool fileReadable(char *path) {
  //Checks if the program has the rights to read the input file

  if (access(path, R_OK)) {
    fprintf(stderr, "File %s is not readable\n", path);
    return false;
  }

  return true;
```

```c
}
bool pathValid(char *path) {
  //Checks if the input path leads to something
  //Currently does not error on a directory

  if (access(path, F_OK)) {
    fprintf(stderr, "File %s does not exist\n", path);
    return false;
  }

  return true;
}

bool correctCallForm(int argc, char *argv[]) {
  //Returns a boolean for if the call is of the right form

  if (argc < 2) {
    fprintf(stderr, "Too few arguments supplied\n");

    return false;
  }

  if (argc > 19) {
    fprintf(stderr, "Too many arguments supplied - 16 files can be combined at
most\n");

    return false;
  }

  if ((!strcmp(argv[1], "-o")) && (argc < 4)) {
    return false;
  }

  return true;
}

int main(int argc, char *argv[]) {
  if (!correctCallForm(argc, argv)) {
    fprintf(stderr, "Usage: catmidi [-o output_path] [path ...]\n");

    return 1;
  }

  bool outputPathGiven = !strcmp(argv[1], "-o");
  char startOfInputs = (outputPathGiven) ? 3 : 1;
  char numberOfInputs = argc - startOfInputs;

  for (int i = startOfInputs; i < argc; i++) {
    if ((!pathValid(argv[i])) || (!fileReadable(argv[i]))) {
      return 1;
    }
  }

  char outputBuffer[65536];
  unsigned char *inputBuffer[numberOfInputs];

  for (int i = 0; i < numberOfInputs; i++) {
    loadFile(argv[i + startOfInputs], &inputBuffer[i]);
  }

  int outputBufferLength = combineMIDIFiles(outputBuffer, inputBuffer,
numberOfInputs);

  for (int i = 0; i < numberOfInputs; i++) {
    free(inputBuffer[i]);
  }

  if (outputBufferLength == 0) {
    return 1;
  }

  FILE *outputFile = fopen((outputPathGiven) ? argv[2] : "./output.midi", "wb");

  if (outputFile == NULL) {
    fprintf(stderr, "Output file could not be created\n");
```

```c
        return 1;
    }

    fwrite(outputBuffer, 1, outputBufferLength, outputFile);
    fflush(outputFile);
    fclose(outputFile);

    return 0;
}
```

catmidi/main.h

```c
#ifndef MAIN_H
#define MAIN_H

struct mthdHeader {
    char chunkType[4];
    int length;
    short format;
    short ntrks;
    short division;
};

struct mtrkHeader {
    char chunkType[4];
    int length;
};

struct mtrkEvent {
    char event[259];
    short length;
    int deltaTime;
};

#endif
```

catmidi/makefile

```makefile
BUILD_DIR = ./build
STD = -std=c99
OPTI = -O3
EXE = catmidi

$(EXE): main.o
    gcc -g -w $(STD) $(OPTI) -o $(BUILD_DIR)/$(EXE) $(BUILD_DIR)/main.o

main.o: main.c
    gcc -c $(STD) $(OPTI) -o $(BUILD_DIR)/main.o main.c

.PHONY: clean

clean:
    rm -f $(BUILD_DIR)/$(EXE)
    rm -f $(BUILD_DIR)/*.o
```
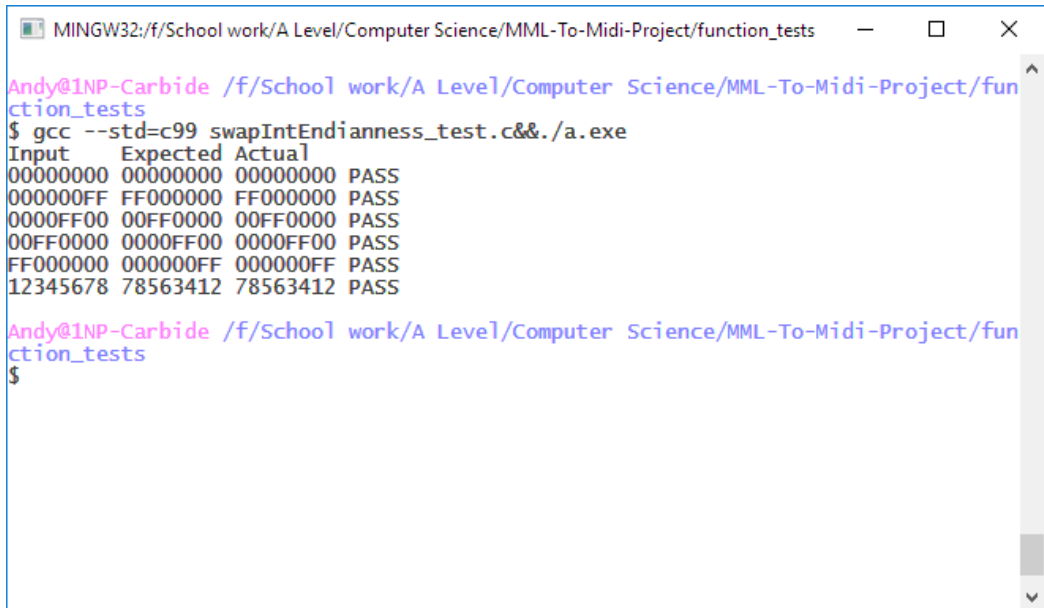
Testing

When I started the project, I planned to use unit testing, and perform test driven development; due to the project making heavy use of the compiler compilers lex and yacc, however, I could not come up with a good way of performing unit testing on my programs. In light of this, I've decided to carry out testing of key functions in isolated source files with tailored test cases.

Function Tests

Function prototype	`int swapIntEndianness(int input)`
Purpose	`Swap the endianness of the integer "input" and return it.`
Testing code	(see code below)

```c
#include <stdio.h>

struct testCase {
    int input;
    int expectedOutput;
};

int swapIntEndianness(int input) {
    int output = 0;

    for (int i = 0; i < 4; i++) {
        *((char *) &output - i + 3) = *((char *) &input + i);
    }

    return output;
}

int main(int argc, char *argv[]) {
    struct testCase tests[] = {{0x00000000, 0x00000000},
                               {0x000000FF, 0xFF000000},
                               {0x0000FF00, 0x00FF0000},
                               {0x00FF0000, 0x0000FF00},
                               {0xFF000000, 0x000000FF},
                               {0x12345678, 0x78563412}};

    int actualOutput;

    printf("Input    Expected Actual  \n");

    for (int i = 0; i < sizeof(tests) / sizeof(struct testCase); i++) {
        actualOutput = swapIntEndianness(tests[i].input);

        printf("%08X %08X %08X", tests[i].input,
tests[i].expectedOutput, actualOutput);

        if (actualOutput != tests[i].expectedOutput) {
            printf(" FAIL\n");

            continue;
        }

        printf(" PASS\n");
    }

    return 0;
}
```

Outcome	

Function prototype	`int writeVariableLengthQuantity(char *outputPtr, int input)`
Purpose	Write the integer "input" as a big endian variable length quantity at the pointer "outputPtr". Return the length of the variable length quantity written.
Testing code	(see code below)

```c
#include <stdio.h>

struct testCase {
    int input;
    int expectedVLQ;
    int expectedReturn;
};

int writeVariableLengthQuantity(char *outputPtr, int input) {
    if (input == 0) {
        *outputPtr = 0;
        return 1;
    }

    int length = 5;

    for (int i = 4; i >= 0; i--) {
        if (input >> i * 7) {
            break;

        } else {
            length--;
        }
    }

    for (int i = length - 1; i >= 0; i--) {
        if (i != 0) {
            *(outputPtr + length - i - 1) = ((input >> i * 7) & 0x7F) +
0x80;

        } else {
            *(outputPtr + length - i - 1) = (input >> i * 7) & 0x7F;
        }
    }

    return length;
}
```

```c
int main(int argc, char *argv[]) {
    struct testCase tests[] = {{0x00000000, 0x00000000, 0},
                               {0x00000040, 0x00000040, 1},
                               {0x0000007F, 0x0000007F, 1},
                               {0x00000080, 0x00000081, 2},
                               {0x00002000, 0x000000C0, 2},
                               {0x00003FFF, 0x00007FFF, 2},
                               {0x00004000, 0x00008081, 3},
                               {0x00100000, 0x000080C0, 3},
                               {0x001FFFFF, 0x007FFFFF, 3},
                               {0x00200000, 0x00808081, 4},
                               {0x08000000, 0x008080C0, 4},
                               {0x0FFFFFFF, 0x7FFFFFFF, 4}};

    int actualVLQ;
    int actualReturn;

    printf("Input     Expected Expected Actual   Actual  \n");
    printf("          VLQ      Return   VLQ       Return  \n");

    for (int i = 0; i < sizeof(tests) / sizeof(struct testCase); i++) {
        actualVLQ = 0;
        actualReturn = writeVariableLengthQuantity((char *) &actualVLQ,
tests[i].input);

        printf("%08X %08X %08X %08X %08X", tests[i].input,
tests[i].expectedVLQ, tests[i].expectedReturn, actualVLQ, actualReturn);

        if (actualVLQ != tests[i].expectedVLQ) {
            printf(" FAIL\n");

            continue;
        }

        printf(" PASS\n");
    }

    printf("\nNOTE: All VLQ values corrected for endianness\n");

    return 0;
}
```
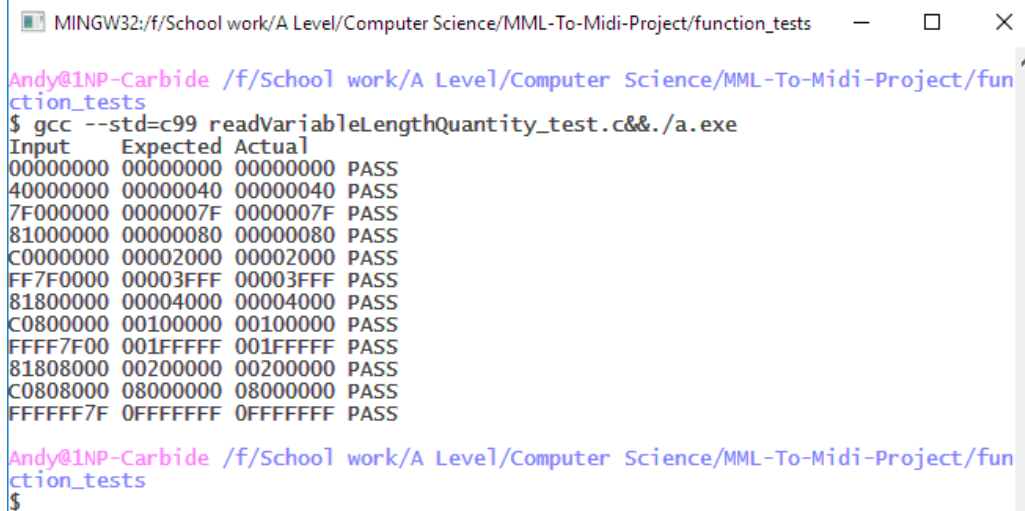
Outcome	

Function prototype	`int readVariableLengthQuantity(char *inputPtr)`
Purpose	Read a big endian variable length quantity from pointer "inputPtr", and return it as a little endian integer.
Testing code	(see code below)

```c
#include <stdio.h>

struct testCase {
    char input[4];
    int expectedOutput;
};

int readVariableLengthQuantity(char *inputPtr) {
    char *workingPtr = inputPtr;

    while (*workingPtr & 0x80) {
        workingPtr++;
    }

    int output = 0;
    int outputShift = 0;

    do {
        output |= (*workingPtr & 0x7F) << outputShift;

        outputShift += 7;

    } while (workingPtr-- != inputPtr);

    return output;
}

int main(int argc, char *argv[]) {
    struct testCase tests[] = {{{0x00, 0x00, 0x00, 0x00}, 0},
                               {{0x40, 0x00, 0x00, 0x00}, 0x40},
                               {{0x7F, 0x00, 0x00, 0x00}, 0x7F},
                               {{0x81, 0x00, 0x00, 0x00}, 0x80},
                               {{0xC0, 0x00, 0x00, 0x00}, 0x2000},
                               {{0xFF, 0x7F, 0x00, 0x00}, 0x3FFF},
                               {{0x81, 0x80, 0x00, 0x00}, 0x4000},
                               {{0xC0, 0x80, 0x00, 0x00}, 0x100000},
                               {{0xFF, 0xFF, 0x7F, 0x00}, 0x1FFFFF},
                               {{0x81, 0x80, 0x80, 0x00}, 0x200000},
                               {{0xC0, 0x80, 0x80, 0x00}, 0x8000000},
                               {{0xFF, 0xFF, 0xFF, 0x7F}, 0xFFFFFFF}};

    int actualOutput;

    printf("Input    Expected Actual  \n");

    for (int i = 0; i < sizeof(tests) / sizeof(struct testCase); i++) {
        actualOutput = readVariableLengthQuantity(tests[i].input);

        for (char c = 0; c < 4; c++) {
            printf("%02X", (unsigned char) tests[i].input[c]);
        }

        printf(" %08X %08X", tests[i].expectedOutput, actualOutput);

        if (actualOutput != tests[i].expectedOutput) {
            printf(" FAIL\n");

            continue;
        }

        printf(" PASS\n");
    }

    return 0;
}
```

Outcome	

mmltomidi Lexer and Parser Test

In order the test the parsing of the mmltomidi program, I have added the code below to its "int main" function. This code will print out the contents of the "mmlFileStruct" structure written to by the parser.
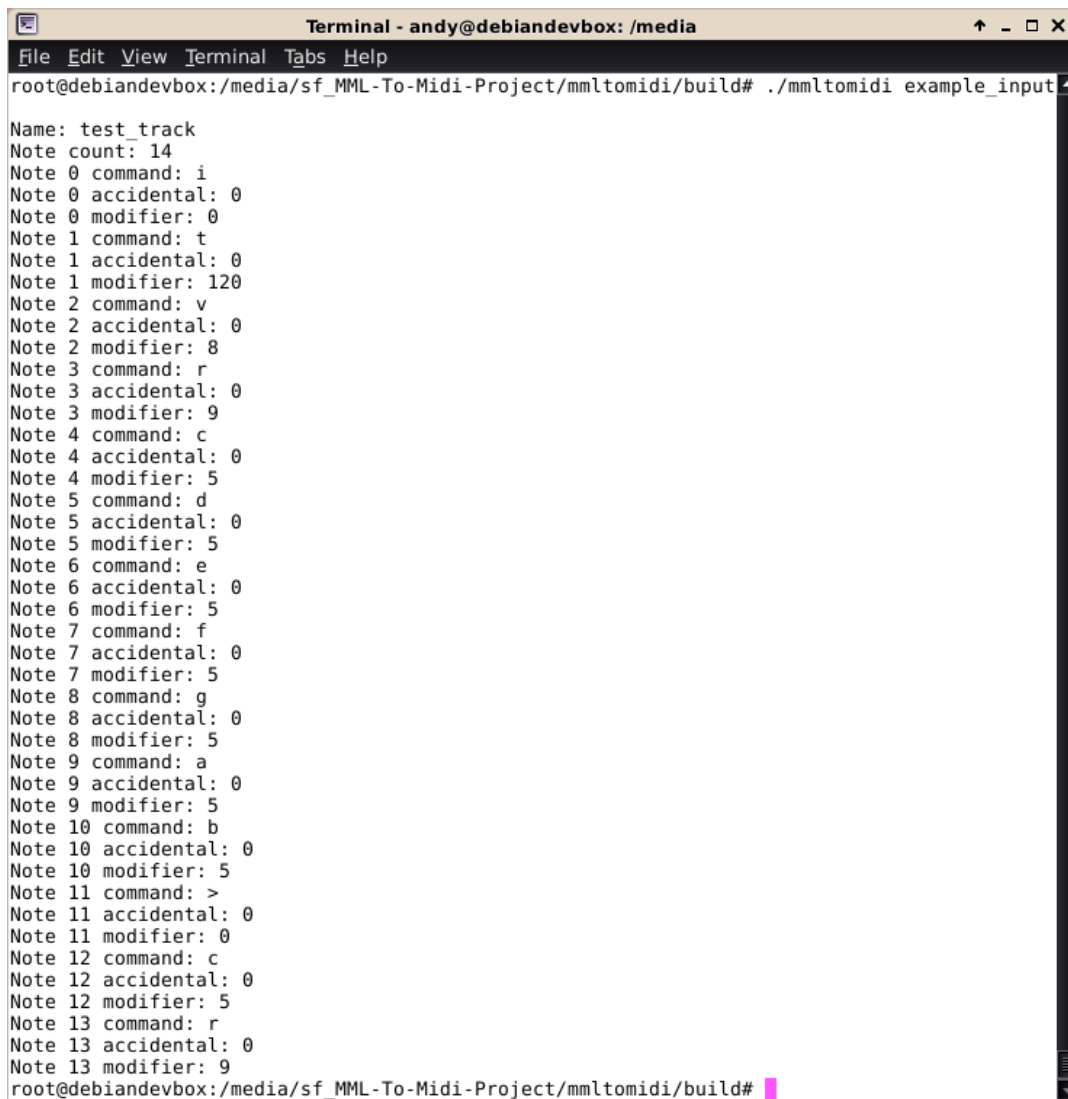
```
printf("Name: %s\n", processedMmlFile.name);
printf("Note count: %d\n", processedMmlFile.noteCount);

for (int i = 0; i < processedMmlFile.noteCount; i++) {
        printf("Note %d command: %c\n", i, processedMmlFile.notes[i].command);
        printf("Note %d accidental: %d\n", i, processedMmlFile.notes[i].accidental);
        printf("Note %d modifier: %d\n", i, processedMmlFile.notes[i].modifier);
}
```

Shown below is a screenshot of the modified mmltomidi program being run, with the example MML file from the design section as an input.

Cross referencing this result with the input, it can be seen that the parser is working correctly.

mmltomidi User Interface Test

In this section, the mmltomidi program will be called in a variety of ways in order to test its user interface, and also the handling of invalid inputs. These test calls are shown in the screenshot below.

Looking at the tests above, the mmltomidi program appears to comply with the user interface specified in the design section, and give appropriate errors when the calling syntax is incorrect.

mmltomidi Full Integration Test

In this test, the mmltomidi program will be tested as a whole. The screenshot below shows the program being run with the example MML file shown in the design section.

The hex dump of the MIDI file outputted from this execution is shown below.
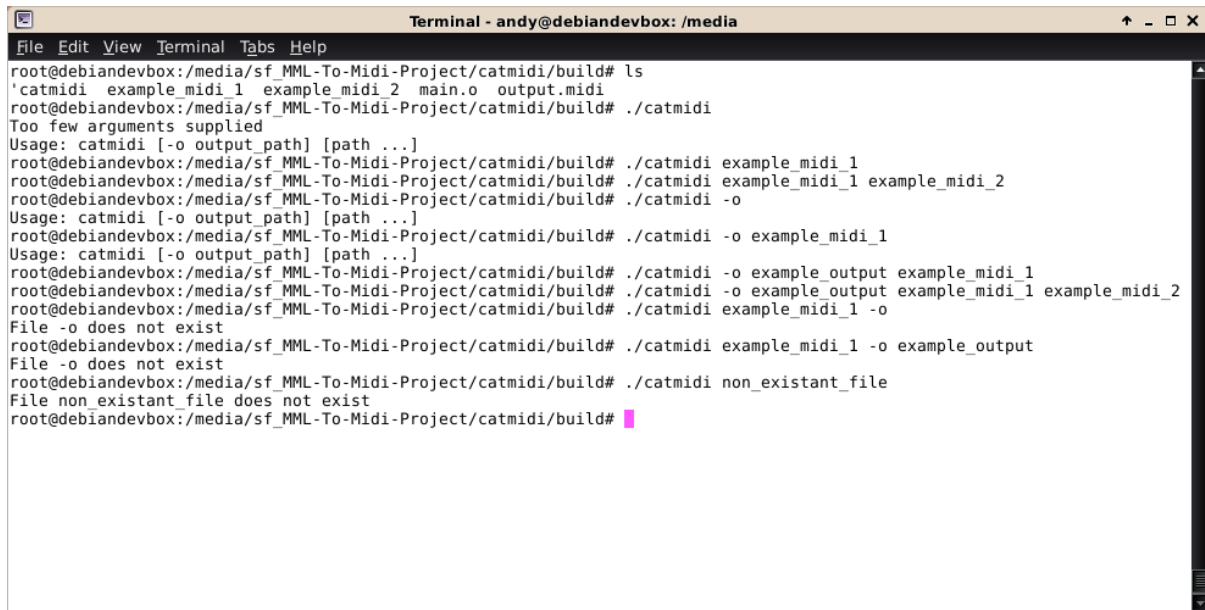
```
4D 54 68 64 00 00 00 06 00 00 00 01 00 08 4D 54 72 6B 00 00 00 7E 00 FF 03 0A 74 65 73 74
5F 74 72 61 63 6B 00 FF 58 04 04 02 18 08 00 FF 51 03 03 D0 90 00 C0 00 00 C0 00 00 FF 51
03 03 D0 90 00 90 00 00 20 80 00 00 00 90 3C 70 08 80 3C 70 00 90 3E 70 08 80 3E 70 00 90
40 70 08 80 40 70 00 90 41 70 08 80 41 70 00 90 43 70 08 80 43 70 00 90 45 70 08 80 45 70
00 90 47 70 08 80 47 70 00 90 48 70 08 80 48 70 00 90 00 00 20 80 00 00 00 FF 2F 00
```

Cross referencing against the expected MIDI file to be outputted by the program in the design section, the program can be verified to be giving the correct output.

catmidi User Interface Test

In this section, the catmidi program will be called in a variety of ways in order to test its user interface, and its behaviour towards invalid calling syntax. These tests are shown in the screenshot below.

Observing the tests above, it can be seen that the catmidi programs user interface functions as described in the design section of this document.

catmidi Full Integration Test

The catmidi program will be tested as a whole in this section. The screenshot below shows a call to the program with inputs "example_midi_1.midi" and "example_midi_2.midi".

The MML code used to generate these example inputs and their hex dumps are shown in the tables below.

example_midi_1.midi	
MML code:	##Example comment #name example #instrument 0 #tempo 120 $c cdefgab>c play r9$cr9
Hex dump:	4D 54 68 64 00 00 00 06 00 00 00 01 00 08 4D 54 72 6B 00 00 00 7B 00 FF 03 07 65 78 61 6D 70 6C 65 00 FF 58 04 04 02 18 08 00 FF 51 03 03 D0 90 00 C0 00 00 C0 00 00 FF 51 03 03 D0 90 00 90 00 00 20 80 00 00 00 90 3C 7F 08 80 3C 7F 00 90 3E 7F 08 80 3E 7F 00 90 40 7F 08 80 40 7F 00 90 41 7F 08 80 41 7F 00 90 43 7F 08 80 43 7F 00 90 45 7F 08 80 45 7F 00 90 47 7F 08 80 47 7F 00 90 48 7F 08 80 48 7F 00 90 00 00 20 80 00 00 00 FF 2F 00

example_midi_2.midi	
MML code:	##Example comment #name example #instrument 0 #tempo 120 $c cdefgab>c play r9>$cr9
Hex dump:	4D 54 68 64 00 00 00 06 00 00 00 01 00 08 4D 54 72 6B 00 00 00 7B 00 FF 03 07 65 78 61 6D 70 6C 65 00 FF 58 04 04 02 18 08 00 FF 51 03 03 D0 90 00 C0 00 00 C0 00 00 FF 51 03 03 D0 90 00 90 00 00 20 80 00 00 00 90 48 7F 08 80 48 7F 00 90 4A 7F 08 80 4A 7F 00 90 4C 7F 08 80 4C 7F 00 90 4D 7F 08 80 4D 7F 00 90 4F 7F 08 80 4F 7F 00 90 51 7F 08 80 51 7F 00 90 53 7F 08 80 53 7F 00 90 54 7F 08 80 54 7F 00 90 00 00 20 80 00 00 00 FF 2F 00

Finally, a hex dump of the combined MIDI outputted by the catmidi program is shown below.

```
4D 54 68 64 00 00 00 06 00 00 00 01 00 08 4D 54 72 6B 00 00 00 DB 00 FF 03 07 65 78 61 6D
70 6C 65 00 FF 58 04 04 02 18 08 00 FF 51 03 03 D0 90 00 C0 00 00 C0 00 00 FF 51 03 03 D0
90 00 90 00 00 00 FF 51 03 03 D0 90 00 C1 00 00 C1 00 00 FF 51 03 03 D0 90 00 91 00 00 20
80 00 00 00 90 3C 7F 00 81 00 00 00 91 48 7F 08 80 3C 7F 00 90 3E 7F 00 81 48 7F 00 91 4A
7F 08 80 3E 7F 00 90 40 7F 00 81 4A 7F 00 91 4C 7F 08 80 40 7F 00 90 41 7F 00 81 4C 7F 00
91 4D 7F 08 80 41 7F 00 90 43 7F 00 81 4D 7F 00 91 4F 7F 08 80 43 7F 00 90 45 7F 00 81 4F
7F 00 91 51 7F 08 80 45 7F 00 90 47 7F 00 81 51 7F 00 91 53 7F 08 80 47 7F 00 90 48 7F 00
81 53 7F 00 91 54 7F 08 80 48 7F 00 90 00 00 00 81 54 7F 00 91 00 00 20 80 00 00 00 FF 2F
00
```

Examining this combined file, it can be seen that the catmidi program functions as it should. Also, listening to the output with a MIDI player, I can hear that the two input MIDI files have been correctly combined.

Evaluation

Completion of the Objectives

Objective	Evaluation
A program should be written that takes text file containing a variant of the MML as an input, and outputs a single-channel MIDI file that can be play with conventional software.	I completed this objective through the writing of the mmltomidi program.
A program should be written that takes multiple MIDI files generated by the aforementioned program and combines them into a single multi-channel MIDI file. This combined MIDI file should be playable using conventional software also.	I completed this objective with the writing of the catmidi program.
The programs written for this project should: • Complete their execution in under one second, so as to not interrupt the users work flow • Use less than half a megabyte of memory during execution • Be a less than a quarter of a megabyte in size	I met all of these objectives: • Both programs complete their execution in well under one second, even when compiled without any optimisation. • While it depends on the size of the files given as inputs to the programs, both programs generally use well under 512 kilobytes of memory. • Combined, the programs take up less than 60 kilobytes of disk spaces

A version of the music macro language should be designed that will be used as the input for the program that generates a single-channel MIDI file from a single MML file. This language should:
 	
 • Have all the functionality of existing variants of the MML, including support for:
     o Octave changing
     o Accidentals
     o Default length setting
     o Volume changing
     o Tempo setting
     o Macros
 	
 • Have as unambiguous a syntax as possible, with a clear logical progression
	I completed this objective in my design section. The language I designed there exceeds the functionality of most MML versions with the inclusion of transposition. It also is necessarily unambiguous as a BNF grammar had to be written for it.

Evaluation of Development

I believe that the development of the project went well – the use of Lex, Yacc and makefiles all proved to be good decisions, as each saved me a great deal of time. An area that was notably lacking during development however was testing. I feel that I could have done more during the writing of my code.

Also, it would have been very useful to have a proper debugging facility during development, as I am confident this would have saved time.

What I Would Change

If I were to do the project again I would implement a better system for testing my programs, though I am still unsure of how this would be achieved. I would also consider the idea of developing a single program to solve the problem, as having two programs to use has proved to be tedious at times. Finally, I would like to add more functionality to the music description language designed for the project, and perhaps make it more similar to a programming language: this could be achieved with the inclusion of loops, variables and control structures.

<u>Bibliography</u>

49

[1] The MIDI Manufacturers Association
The Complete MIDI 1.0 Detailed Specification
Version 96.1, Third Edition (1996)

[2] John R. Levine, Tony Mason & Doug Brown
lex & yacc
Second Edition (1995)

[3] Brian W. Kernighan, Dennis M. Ritchie
The C Programming Language
Second Edition (1988)