# CHASM

Version 1.0 Manual
By Matthew Mikolay

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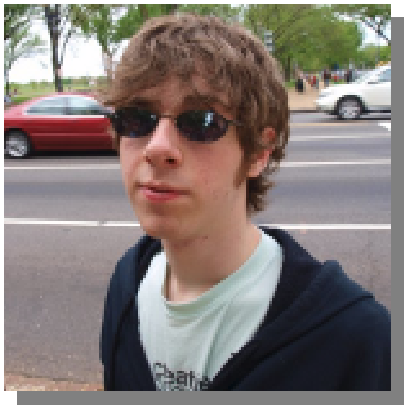
## About the Author



*December 24th, 2010*
Matthew James Mikolay is currently a student living in New Jersey. His interests include computer science, and specifically, the design and interpretation of programming languages.

Matthew has a strong passion for vintage computers and their history. He is currently a member of the MidAtlantic Retro Computing Hobbyists (MARCH).

Matthew Mikolay is the founder and maintainer for the RCA COSMAC VIP Yahoo! Group (`http://groups.yahoo.com/group/rcacosmac`), which is dedicated to the preservation of the COSMAC VIP and related computers.

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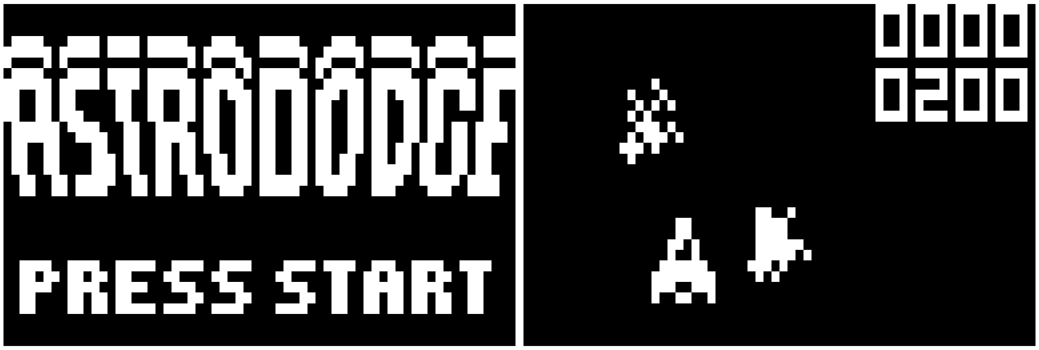
## Introduction

CHIP-8 is an interpreted programming language initially developed by Joseph Weisbecker for the COSMAC VIP computer in 1977. Created to simplify the programming of video games, CHIP-8 was popular and portable for the computers of its generation. As a result, a variety of games have been developed in the CHIP-8 language.



An example of a game programmed in CHIP-8*

CHIP-8 allows graphical output to a sixty-four by thirty-two monochrome pixel display. One sound timer triggers the playing of a monotone frequency, and one delay timer can be used for scheduling. A sixteen-key hexadecimal keypad is used for input. Sixteen eight-bit data registers can be used to store data, and the sixteen-bit address register can be used to store a memory address.

The portability of the CHIP-8 language is due to the fact that it is an interpreted hexadecimal language. All CHIP-8 instructions are hexadecimal numbers and can be easily stored and read in memory. However, programming in CHIP-8 has often been perceived as a difficult task due to this hexadecimal format, as the purpose of each instruction in a program is not immediately evident. Because of this, the need for a CHIP-8 pseudo-assembler arises.

The CHIP-8 language is an interpreted programming language, as its instructions are read by an interpreting program, which then executes corresponding code on the host computer. chasm presents the CHIP-8 language to a programmer using a system of easy-to-read and remember mnemonics, which are then translated into the traditional interpreted CHIP-8 opcodes. Because the chasm mnemonics are translated into an interpreted language rather than a machine language, chasm is known as a pseudo-assembler instead of a regular assembler.

Although this difference may be important, it over-complicates the matters that this manual concerns. Therefore, the mnemonic language used by chasm will be identified as assembly language from this point on, and the interpreted programming language that chasm outputs will be identified as machine language or machine code.

* *Astro Dodge* programming and graphics by Martijn Wenting, Revival Studios, www.revival-studios.com

## Features

chasm is a pseudo-assembler for the CHIP-8 programming language. It was designed to accept a text file containing 'assembly language' mnemonics as input, and output the resulting CHIP-8 'machine code' to a separate file.

Version 1.0 of chasm supports all thirty-five original CHIP-8 commands defined by Joseph Weisbecker for the COSMAC VIP computer. These commands and their corresponding assembly language mnemonics are found in the table on the next page.

chasm also supports an additional command called the `.START` command, used to specify the memory address at which the resulting CHIP-8 program should be loaded on the host machine. This designated value is used by chasm to determine the values of label addresses during the label linking process. Although the `.START` command is completely optional, it should be the first command found in the input file when present. This additional command is highlighted in red in the table on the next page.

chasm  supports two other commands, the `DB` and `DW` commands, which accept an 8-bit value and a 16-bit value respectively as arguments. These commands insert the given argument into the generated output code at the corresponding address, and can be used to insert graphics data into CHIP-8 assembly source code. These additional commands are highlighted in red in the table on the next page.

## Supported Instructions

- *Code in { } brackets designate optional parameters for an instruction.*
- *Vx and Vy are register names, kk is a byte, nnn is an address, n is a nibble.*
- *Mnemonics in red represent commands specific to chasm, and not implemented by the original CHIP-8 specification.*

| Opcode | Mnemonic |
|---|---|
| 00E0 | CLS |
| 00EE | RET |
| 0nnn | SYS <addr> |
| 1nnn | JP <addr> |
| 2nnn | CALL <addr> |
| 3xkk | SE <Vx>, <byte> |
| 4xkk | SNE <Vx>, <byte> |
| 5xy0 | SE <Vx>, <Vy> |
| 6xkk | LD <Vx>, <byte> |
| 7xkk | ADD <Vx>, <byte> |
| 8xy0 | LD <Vx>, <Vy> |
| 8xy1 | OR <Vx>, <Vy> |
| 8xy2 | AND <Vx>, <Vy> |
| 8xy3 | XOR <Vx>, <Vy> |
| 8xy4 | ADD <Vx>, <Vy> |
| 8xy5 | SUB <Vx>, <Vy> |
| 8xy6 | SHR <Vx> {, <Vy>} |
| 8xy7 | SUBN <Vx>, <Vy> |
| 8xyE | SHL <Vx> {, <Vy>} |
| 9xy0 | SNE <Vx>, <Vy> |
| Annn | LD I, <addr> |
| Bnnn | JP V0, <addr> |
| Cxkk | RND <Vx>, <byte> |
| Dxyn | DRW <Vx>, <Vy>, <nibble> |
| Ex9E | SKP <Vx> |
| ExA1 | SKNP <Vx> |
| Fx07 | LD <Vx>, DT |
| Fx0A | LD <Vx>, K |
| Fx15 | LD DT, <Vx> |
| Fx18 | LD ST, <Vx> |
| Fx1E | ADD I, <Vx> |
| Fx29 | LD F, <Vx> |
| Fx33 | LD B, <Vx> |
| Fx55 | LD [I], <Vx> |
| Fx65 | LD <Vx>, [I] |
| ---- | **.START <addr>** |
| ---- | **DB <byte>** |
| ---- | **DW <word>** |

## Example Output

The following table contains a side-by-side comparison of two files: input.asm, a text file containing assembly language mnemonics, and output.c8, a data file containing corresponding CHIP-8 machine language opcodes. Each line (or lines) of input.asm has its corresponding CHIP-8 opcode printed directly adjacent under the output.c8 column. input.asm is printed as if viewed in a standard ASCII text editor, and output.c8 is printed as if viewed in a hexadecimal editor with a byte-span value of 2. It should be noted that CHIP-8 commands are stored using big-endian mode, with the most-significant byte first and the least-significant byte last.

| **input.asm** | **output.c8** |
|---|---|
| START: CLS | 00E0 |
| RND V0, #FF | C0FF |
| LD I, #224 | A224 |
| LD B, V0 | F033 |
| LD V2, [I] | F265 |
| LD F, V0 | F029 |
| LD V0, #00 | 6000 |
| LD V3, #00 | 6300 |
| DRW V0, V3, 5 | D035 |
| LD F, V1 | F129 |
| LD V0, #05 | 6005 |
| DRW V0, V3, 5 | D035 |
| LD F, V2 | F229 |
| LD V0, 10 | 600A |
| DRW V0, V3, 5 | D035 |
| LD V0, K | F00A |
| JP START | 1200 |
| | |
| DB #FF | FFEA |
| DB #EA | |
| | |
| DW #21AC | 21AC |

## Proper Usage

chasm accepts two files: an input file and an output file. The lines stored in the input file are read and converted into corresponding CHIP-8 code, which is then stored in the output file. If an error occurs while opening either the input or output file, an error message is displayed to the user.

The proper syntax for chasm is:

```
    chasm <input filename> <output filename>
```

If this syntax is not followed, an error message, along with the guidelines for the proper syntax, are displayed to the user.

## Design Description

A simplified summary of the overall design of chasm is presented in a flow chart on page 10.

### Initialization

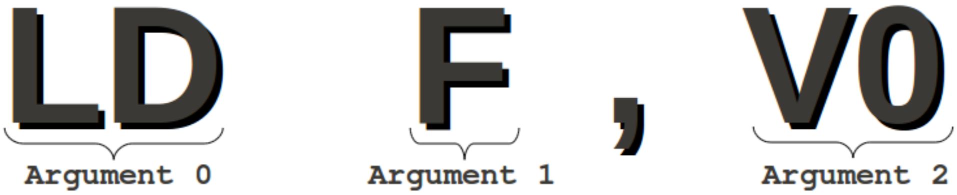
Upon startup, chasm checks to make sure the correct amount of command line arguments were entered and processes them accordingly. chasm is called with the following syntax:

```
    chasm <input filename> <output filename>
```

chasm attempts to open the file passed by the user as input.

### Input Processing

chasm processes the assembly language commands found in the input file by looping through the file and processing each individual line, separating it into sections called "arguments." An argument is any part of an assembly command. The following diagram provides an example:



While separating each line into arguments, chasm checks if a label has been included. If one is found, a label is created, and the corresponding argument is removed from the argument array. This allows processing of the line to continue regardless of the created label.

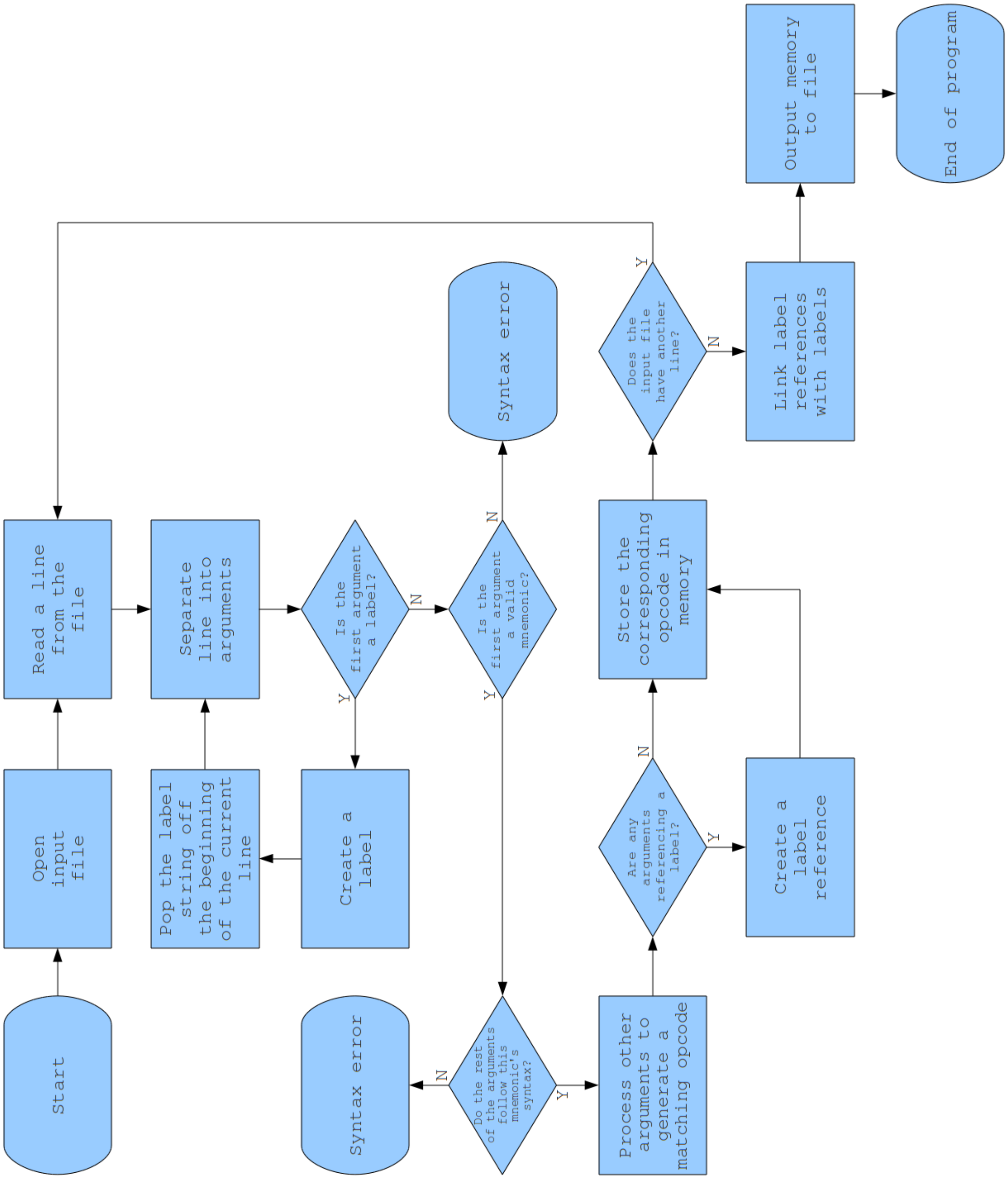
After the line has been separated into arguments and any present labels have been removed, chasm begins processing the arguments and generating the resulting machine code. If an error is found in the syntax of the arguments, or the assembler undergoes an error, relevant information is printed to the screen.

### Label Linking

After the entire input file has been processed, any references to labels made by assembly language commands will have been stored in a label reference array. chasm loops through this array, checking to make sure that each label referenced actually exists, and linking the identified labels with their corresponding memory addresses.

### File Output

chasm has now finished generating machine code corresponding to the assembly instructions found in the input file. This machine code is sent to the designated output file for storage, and the program reaches completion.


Start
Open input file
Read a line from the file
Separate line into arguments
Is the first argument a label?
Y
Create a label
Pop the label string off the beginning of the current line
N
Is the first argument a valid mnemonic?
N
Syntax error
Y
Do the rest of the arguments follow this mnemonic's syntax?
N
Syntax error
Y
Process other arguments to generate a matching opcode
Are any arguments referencing a label?
Y
Create a label reference
N
Store the corresponding opcode in memory
Does the input file have another line?
Y
N
Link label references with labels
Output memory to file
End of program

## Source Code/Compiling

The following pages contain the complete and unabridged source code for version 1.0 of chasm. Much of the code is documented through the use of in-code comments. The following table describes the functions of the various source files.

| | | |
|---|---|---|
| `chasm.h` | ■ The primary header file for chasm<br>■ Contains functions to perform the following:<br>○ Check for whitespace<br>○ Convert a lowercase character to uppercase<br>○ Output an error<br>○ Add a command argument to an array<br>○ Check if a string is numeric<br>○ Convert strings to numeric data and register data | Page 14 |
| `label.h` | ■ The header file defining the label class | Page 19 |
| `lref.h` | ■ The header file defining the label reference class | Page 21 |
| `chasm.cpp` | ■ The primary source code file for chasm | Page 22 |

chasm should be compiled using a standard C++ compiler. The GNU C++ Compiler (G++) of the GNU Compiler Collection (GCC) is strongly recommended. `chasm.cpp` should be in the same directory as the header files when compiling.

## chasm.h

```
#include <string>              // For the string class
#include <sstream>             // For conversions from string to number
using namespace std;

/*
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    along with chasm.  If not, see <http://www.gnu.org/licenses/>.

*/

// Returns true if a given character is whitespace
bool isWhitespace(char letter)
{
 return (letter == ' ' || letter == '\t');
}

// Converts a given character to uppercase if the input is in lowercase
char toUpper(char letter)
{
 if(letter >= 0x61 && letter <= 0x7A)
        return (letter - 0x20);
 return letter;
}

// Writes to the screen that an error occured
bool error(string filename, unsigned int lineNumber, string message)
{
 cout << filename << ":" << lineNumber << ":" << message << endl;
 return true;
}

// Try to add an argument to the array of arguments, making sure no overflow occurs
bool addArg(string &input, string (&args)[4], unsigned char &number)
{
 // Make sure the maximum number of arguments is not already in the array
 if(number >= 4)
        return false;

 // Store the word, increment the counter, and clear the contents of word
 args[number] = input;
 number++;
 input = "";
 return true;
}

// Returns true if the given string is a number
bool isNumeric(string input)
{
 if(input.at(0) == '#' || input.at(0) == '$')
        return true;

 // Loop through the contents of the string, looking for non-numeric characters
 for(unsigned int i = 0; i < input.length(); i++)
 {
      if(input.at(i) < '0' || input.at(i) > '9')
           return false;
 }

 return true;
}

// Convert a given string to a register number
bool strToRegister(string input, unsigned char &output)
{
 if(input.length() == 2 && input.at(0) == 'V')
 {
      // Is the register a number register?
      if(input.at(1) >= 'A' && input.at(1) <= 'F')
      {
           output = input.at(1) - 55;
           return true;
      }
      // Is the register a letter register?
      if(input.at(1) >= '0' && input.at(1) <= '9')
      {
           output = input.at(1) - '0';
           return true;
      }
 }
 return false;
}

// Convert a given string to a 4-bit number (nibble)
bool strToNibble(string input, unsigned char &output)
{
 if(input.length() > 0)
 {
      // Process the input as hexadecimal
      if(input.at(0) == '#')
      {
           unsigned int result = 0;
           // Remove the hash
           input = input.substr(1, input.length());
           // Attempt to convert the string to a number
           istringstream iss(input);

           // Make sure the conversion did not fail and the result is a 4-bit number
           if((iss >> hex >> result).fail() || result >= 16)
                return false;

           output = result;
           return true;
      }

      // Process the input as binary
      if(input.at(0) == '$')
      {
           unsigned int result = 0;
           // Loop through the string computing the binary number
           for(unsigned char i = input.length() - 1; i > 0; i--)
           {
                if(input.at(i) == '1')
                     result += 1 << (input.length() - 1 - i);
                else if(input.at(i) != '0' && input.at(i) != '.')
                     return false;
           }

           // Make sure the result is a 4-bit number
           if(result >= 16)
                return false;

           output = result;
           return true;
      }

      // Try to process the input as decimal
      else
      {
           unsigned int result = 0;
           // Attempt to convert the string to a number
           istringstream iss(input);

           // Make sure the conversion did not fail and the result is a 4-bit number
           if((iss >> dec >> result).fail() || result >= 16)
                return false;

           output = result;
           return true;
      }
 }
 return false;
}

// Convert a given string to an 8-bit number (byte)
bool strToByte(string input, unsigned char &output)
{
 if(input.length() > 0)
 {
      // Process the input as hexadecimal
      if(input.at(0) == '#')
      {
           unsigned int result = 0;
           // Remove the hash
           input = input.substr(1, input.length());
           // Attempt to convert the string to a number
           istringstream iss(input);

           // Make sure the conversion did not fail and the result is an 8-bit number
           if((iss >> hex >> result).fail() || result >= 256)
                return false;

           output = result;
           return true;
      }

      // Process the input as binary
      if(input.at(0) == '$')
      {
           unsigned int result = 0;
           // Loop through the string computing the binary number
           for(unsigned char i = input.length() - 1; i > 0; i--)
           {
                if(input.at(i) == '1')
                     result += 1 << (input.length() - 1 - i);
                else if(input.at(i) != '0' && input.at(i) != '.')
                     return false;
           }

           // Make sure the result is an 8-bit number
           if(result >= 256)
                return false;

           output = result;
           return true;
      }

      // Try to process the input as decimal
      else
      {
           unsigned int result = 0;
           // Attempt to convert the string to a number
           istringstream iss(input);

                // Make sure the conversion did not fail and the result is an 8-bit number
                if((iss >> dec >> result).fail() || result >= 256)
                        return false;

                output = result;
                return true;
        }
 }
 return false;
}

// Convert a given string to a 12-bit number
bool strTo12Bit(string input, unsigned short &output)
{
 if(input.length() > 0)
 {
        // Process the input as hexadecimal
        if(input.at(0) == '#')
        {
                unsigned int result = 0;
                // Remove the hash
                input = input.substr(1, input.length());
                // Attempt to convert the string to a number
                istringstream iss(input);

                // Make sure the conversion did not fail and the result is a 12-bit number
                if((iss >> hex >> result).fail() || result >= 4096)
                        return false;

                output = result;
                return true;
        }

        // Process the input as binary
        if(input.at(0) == '$')
        {
                unsigned int result = 0;
                // Loop through the string computing the binary number
                for(unsigned char i = input.length() - 1; i > 0; i--)
                {
                        if(input.at(i) == '1')
                                result += 1 << (input.length() - 1 - i);
                        else if(input.at(i) != '0' && input.at(i) != '.')
                                return false;
                }

                // Make sure the result is a 12-bit number
                if(result >= 4096)
                        return false;

                output = result;
                return true;
        }

        // Try to process the input as decimal
        else
        {
                unsigned int result = 0;
                // Attempt to convert the string to a number
                istringstream iss(input);

                // Make sure the conversion did not fail and the result is a 12-bit number
                if((iss >> dec >> result).fail() || result >= 4096)
                        return false;

                output = result;
                return true;
        }
 }
 return false;
```

```
}

// Convert a given string to a 16-bit number
bool strToWord(string input, unsigned short &output)
{
 if(input.length() > 0)
 {
         // Process the input as hexadecimal
         if(input.at(0) == '#')
         {
                 unsigned int result = 0;
                 // Remove the hash
                 input = input.substr(1, input.length());
                 // Attempt to convert the string to a number
                 istringstream iss(input);

                 // Make sure the conversion did not fail and the result is a 16-bit number
                 if((iss >> hex >> result).fail() || result >= 65536)
                         return false;

                 output = result;
                 return true;
         }

         // Process the input as binary
         if(input.at(0) == '$')
         {
                 unsigned int result = 0;
                 // Loop through the string computing the binary number
                 for(unsigned char i = input.length() - 1; i > 0; i--)
                 {
                         if(input.at(i) == '1')
                                 result += 1 << (input.length() - 1 - i);
                         else if(input.at(i) != '0' && input.at(i) != '.')
                                 return false;
                 }

                 // Make sure the result is a 16-bit number
                 if(result >= 65536)
                         return false;

                 output = result;
                 return true;
         }

         // Try to process the input as decimal
         else
         {
                 unsigned int result = 0;
                 // Attempt to convert the string to a number
                 istringstream iss(input);

                 // Make sure the conversion did not fail and the result is a 16-bit number
                 if((iss >> dec >> result).fail() || result >= 65536)
                         return false;

                 output = result;
                 return true;
         }
 }
 return false;
}
```

## label.h

```
/*
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    along with chasm.  If not, see <http://www.gnu.org/licenses/>.

*/

// A class to store label data
class label
{
 private:
         string name;                  // A name to identify the label
         unsigned short address;       // The memory address associated
                                       // with the label name
 public:
         label(string paramName, unsigned short paramAddress);
         label();
         bool isValid();
         string getName();
         unsigned short getAddress();
         ~label();
};

// Label constructor
label::label(string paramName, unsigned short paramAddress)
{
 name    = paramName;
 address = paramAddress;
}

// Label constructor
label::label()
{
}

// Returns true if the label has a valid identifying name
// Labels cannot be numbers of any form, including binary, hexadecimal, and decimal.
// This would interfere with the jump command ("JMP") and prevent
// jumping to specific addresses.
bool label::isValid()
{
 return !isNumeric(name);
}

// Return the label name
string label::getName()
{
 return name;
}

// Return the label address
```

```
unsigned short label::getAddress()
{
 return address;
}

// Label destructor
label::~label(){ }
```

## lref.h

```
/*
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    along with chasm.  If not, see <http://www.gnu.org/licenses/>.

*/

// A class to store label reference data
class lref
{
 private:
        string name;                  // The name of the referenced label
        unsigned short address;       // The memory address of
                                      // this reference
 public:
        lref(string paramName, unsigned short paramAddress);
        lref();
        string getName();
        unsigned short getAddress();
        ~lref();
};

// Label reference constructor
lref::lref(string paramName, unsigned short paramAddress)
{
 name    = paramName;
 address= paramAddress;
}

// Label reference constructor
lref::lref()
{
}

// Return the label reference name
string lref::getName()
{
 return name;
}

// Return the label reference address
unsigned short lref::getAddress()
{
 return address;
}

// Label reference destructor
lref::~lref(){ }
```

## chasm.cpp

```cpp
// Standard C++ libraries
#include <fstream>
#include <iostream>

// chasm specific libraries
#include "chasm.h"
#include "label.h"
#include "lref.h"

/*

 XXXXXXXXXXXX  XXXX    XXXX  XXXXXXXXXXXX  XXXXXXXXXXXX  XXXXXXXXXXXXXXXXXXXX
 XXXXXXXXXXXX  XXXX    XXXX  XXXXXXXXXXXX  XXXXXXXXXXXX  XXXXXXXXXXXXXXXXXXXX
 XXXX    XXXX  XXXX    XXXX  XXXX    XXXX  XXXX          XXXX    XXXX    XXXX
 XXXX          XXXXXXXXXXXX  XXXXXXXXXXXX  XXXXXXXXXXXX  XXXX    XXXX    XXXX
 XXXX          XXXXXXXXXXXX  XXXXXXXXXXXX  XXXXXXXXXXXX  XXXX    XXXX    XXXX
 XXXX    XXXX  XXXX    XXXX  XXXX    XXXX          XXXX  XXXX    XXXX    XXXX
 XXXXXXXXXXXX  XXXX    XXXX  XXXX    XXXX  XXXXXXXXXXXX  XXXX    XXXX    XXXX
 XXXXXXXXXXXX  XXXX    XXXX  XXXX    XXXX  XXXXXXXXXXXX  XXXX    XXXX    XXXX

                                VERSION 1.0

             Dedicated to the amazingly sweet Melanie Ridgway. <3

                                   Love,
                                     Matt

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    along with chasm.  If not, see <http://www.gnu.org/licenses/>.

*/

int main(int argc, char *argv[])
{
 // Create needed variables
 unsigned short start          = 0x200;       // Starting value of the program counter
 unsigned short offset         = 0x000;       // Program counter offset from the starting address, initially zero
 unsigned char  memory[4096];                 // Memory to store CHIP-8 machine code
 string         i_file  = "input.asm";        // The filename of the input file
 string         o_file  = "output.c8";        // The filename of the output file
 bool           eflag   = false;              // Signal if an error has occured

 // ***************************************
 // Begin processing command line arguments
 // ***************************************

 // Syntax: chasm <input filename> <output filename>

 // Make sure the correct number of command line arguments is present
```

```
if(argc != 3)
{
        // Return an error message
        eflag = error("chasm 1.0", 0, "Incorrect command line argument usage.\n\nSyntax:\n\tchasm <input filename> <output filename>");
        // Exit the program
        return false;
}

// Set the input and output filenames
i_file = argv[1];
o_file = argv[2];

// **************************************
// Begin reading data from the input file
// **************************************

// Open the source file for reading
ifstream source;
source.open(i_file.c_str(), ifstream::in);

// Check if the source file has not been opened correctly
if(!source.is_open())
{
        // Return an error message
        eflag = error(i_file, 0, "File error. Could not open file \"" + i_file + "\" for input.");
        // Exit the program
        return false;
}

// Create arrays and variables to store label data and references
const unsigned int list_labels_size = 256;    // The maximum number of labels capable of being processed by chasm
const unsigned int list_lrefs_size  = 256;    // The maximum number of label references capable of being processed by chasm

label list_labels[list_labels_size];          // An array to store labels
lref  list_lrefs [list_lrefs_size];           // An array to store label references

unsigned char  num_labels     = 0;            // The current number of labels stored in list_labels
unsigned char  num_lrefs      = 0;            // The current number of label references stored in list_lrefs

// Create a string to store line contents
string line = "";

// Create a string to store the current word of a line
string word;

// Create a string array to store the arguments
// argument[0] is the command name (I.E. "SE", "DRW", "LD", etc.)
// argument[1 ... 3] are command parameters (I.E. "V1", "#4A", etc.)
// Note:       The current version of CHIP-8 assembly processed by chasm
//             supports a maximum of four arguments, as no mnemonics
//             process more than this number.
string arguments[4];

// Create an integer to store the number of arguments currently stored in the array
unsigned char numArgs;

// Create an integer to store the line number of the line being currently read
unsigned int lineNumber = 0;

// ************************************************
// Begin processing the current line into arguments
// ************************************************

// Loop through the lines of the source file
while(!source.eof())
```

```
{
        // Get the next line from the source file
        getline(source, line);

        // Reset the value of the current word string and the number of arguments
        word    = "";
        numArgs = 0;

        // Increase the line number
        lineNumber++;

        // Loop through the line, storing arguments and looking for labels
        for(unsigned char i = 0; i < line.length(); i++)
        {
                // If the current character is a semicolon, process the rest of the line as a comment
                if(line.at(i) == ';')
                {
                        // If word has data in it, store it
                        if(word.length() != 0)
                        {
                                if(!addArg(word, arguments, numArgs))
                                {
                                        // Return an error message
                                        eflag = error(i_file, lineNumber, "Syntax error. Argument array overflow. Check line?");
                                        // Exit the program
                                        return false;
                                }
                        }

                        // Stop processing the rest of the line
                        break;
                }

                // If the current character is a colon, process the stored word as a label
                if(line.at(i) == ':')
                {
                        // Make sure the colon was placed correctly
                        if(word == "")
                        {
                                // Incorrect colon usage
                                eflag = error(i_file, lineNumber, "Syntax error. Check colon usage.");
                                // Read the next line
                                break;
                        }

                        // Try to store the word
                        if(!addArg(word, arguments, numArgs))
                        {
                                // Return an error message
                                eflag = error(i_file, lineNumber, "Syntax error. Argument array overflow.");
                                // Exit the program
                                return false;
                        }

                        // Make sure only one word has been stored
                        if(numArgs != 1)
                        {
                                // Return an error message
                                eflag = error(i_file, lineNumber, "Syntax error. Check label identifier.");
                                // Exit the program
                                return false;
                        }

                        // Create a new label
                        label myLabel = label(arguments[0], offset);

```

```
            // If the label has an invalid name, return an error
            if(!myLabel.isValid())
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Label error. Invalid label identifier.");
                // Exit the program
                return false;
            }

            // Make sure a label with the same name has not already been inserted into the array
            for(unsigned int curLblNum = 0; curLblNum < num_labels; curLblNum++)
            {
                if(myLabel.getName() == list_labels[curLblNum].getName())
                {
                    // Return an error message
                    eflag = error(i_file, lineNumber, "Syntax error. Label \"" + myLabel.getName() + "\" already exists.");
                    // Exit the program
                    return false;
                }
            }

            // Make sure no array overflow will occur
            if(num_labels >= list_labels_size)
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Assembler error. Label array overflow. Maximum number of labels reached.");
                // Exit the program
                return false;
            }

            // Add the current label to the list for storage
            list_labels[num_labels] = myLabel;
            num_labels++;

            // ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
            // Enable the following line to signal the creation of a new label
            // ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
            // cout << "Label \"" << arguments[0] << "\" created at address " << offset << "!" << endl;

            // Reset the value of word
            word = "";

            // Process the rest of the line as if the label has been removed
            numArgs = 0;

            continue;
        }

        // If the current character is a comma, and parameters are currently being read, store the word
        if(line.at(i) == ',' && word != "")
        {
            // Detect if the comma was unnecessary, as no other arguments have been stored yet
            if(numArgs == 0)
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Syntax error. Unnecessary comma?");
                // Exit the program
                return false;
            }

            // Store the current word
            if(!addArg(word, arguments, numArgs))
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Syntax error. Argument array overflow.");
                // Exit the program
                return false;
            }
        }

        // If the current character is not whitespace, add the uppercase version of the current character to the word
        else if(!isWhitespace(line.at(i)))
            word += toUpper(line.at(i));

        // If whitespace is encountered, word is not empty, and no arguments
        // Are currently stored, then store the first word as a command
        else if(word.length() != 0 && numArgs == 0 && isWhitespace(line.at(i)))
        {
            if(!addArg(word, arguments, numArgs))
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Syntax error. Argument array overflow. Check line?");
                // Exit the program
                return false;
            }
            continue;
        }

        // If this is the end of the line, and word contains data, store it depending upon if we are storing commands or parameters
        if(i == line.length() - 1)
        {
            // If the final character is a comma, return an error
            if(line.at(i) == ',')
            {
                // Return an error message
                eflag = error(i_file, lineNumber, "Syntax error. Unnecessary comma?");
                // Exit the program
                return false;
            }

            if(word != "")
            {
                // Store the current word
                if(!addArg(word, arguments, numArgs))
                {
                    // Return an error message
                    eflag = error(i_file, lineNumber, "Syntax error. Argument array overflow. Check line?");
                    // Exit the program
                    return false;
                }
            }
        }
    }

    // +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
    // Enable the following lines of code to output all arguments to the screen
    // +++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

    // cout << endl;
    // for(unsigned char a = 0; a < numArgs; a++)
    //      cout << arguments[a] << "\t";


    // ***********************************************************
    // Begin processing the arguments and generating machine code
    // ***********************************************************

```

```
        // Check if at least one argument was entered
        if(numArgs > 0)
        {
            // Process all single argument commands
            if(numArgs == 1)
            {
                // CLS - 00E0
                if(arguments[0] == "CLS")
                {
                    // Add corresponding machine code to memory
                    memory[offset] = 0x00; offset++;
                    memory[offset] = 0xE0; offset++;
                    // Read the next line
                    continue;
                }

                // RET - 00EE
                if(arguments[0] == "RET")
                {
                    // Add corresponding machine code to memory
                    memory[offset] = 0x00; offset++;
                    memory[offset] = 0xEE; offset++;
                    // Read the next line
                    continue;
                }

                // Unknown command
                eflag = error(i_file, lineNumber, "Syntax error. Unknown command \"" + arguments[0] + "\".");
                // Read the next line
                continue;
            }

            // Process all double argument commands
            if(numArgs == 2)
            {
                // Macro: .START ADDR
                // Signifies start address
                if(arguments[0] == ".START")
                {
                    // Make sure no other commands have been entered yet
                    if(offset != 0)
                    {
                            // Return an error message
                            eflag = error(i_file, lineNumber, "Assembler error. Input code attempts to modify start address after other commands have been processed.");
                            // Exit the program
                            return false;
                    }

                    unsigned short result = 0x0000;
                    // Try to convert the second argument into an address
                    if(!strTo12Bit(arguments[1], result))
                    {
                            // Return an error message
                            eflag = error(i_file, lineNumber, "Syntax error. Invalid number \"" + arguments[1] + "\" designated as start address.");
                            // Exit the program
                            return false;
                    }

                    // Set the start address
                    start = result;

                    // Read the next line
                    continue;
                }

                // DB BYTE
                // Store a byte
                if(arguments[0] == "DB")
                {
                    unsigned char result = 0x00;
                    // Try to convert the second argument into a byte
                    if(!strToByte(arguments[1], result))
                    {
                        // Invalid argument
                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\". Expected an 8-bit number.");
                        // Read the next line
                        continue;
                    }

                    memory[offset] = result;
                    offset++;

                    // Read the next line
                    continue;
                }

                // DW WORD
                // Store a word
                if(arguments[0] == "DW")
                {
                    unsigned short result = 0x0000;
                    // Try to convert the second argument into a byte
                    if(!strToWord(arguments[1], result))
                    {
                        // Invalid argument
                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\". Expected a 16-bit number.");
                        // Read the next line
                        continue;
                    }

                    memory[offset] = (unsigned char)(result >> 8);      offset++;
                    memory[offset] = (unsigned char)(result & 0x00FF);  offset++;

                    // Read the next line
                    continue;
                }

                // SYS ADDR - 0NNN
                if(arguments[0] == "SYS")
                {
                    unsigned short result = 0x0000;
                    // Try to convert the second argument into an address
                    // If that fails, process the second argument as a label reference
                    if(!strTo12Bit(arguments[1], result))
                    {
                        // Create a new label reference
                        lref myLref = lref(arguments[1], offset);

                        // Make sure no array overflow will occur
                        if(num_lrefs >= list_lrefs_size)
                        {
                            // Return an error message
                            eflag = error(i_file, lineNumber, "Assembler error. Label reference array overflow. Maximum number of label references reached.");
                            // Exit the program
                            return false;
                        }

                        // Add the current label to the list for storage
                        list_lrefs[num_lrefs] = myLref;
                        num_lrefs++;
                    }

                    // Add corresponding machine code to memory
                    memory[offset] = 0x00 + ((result & 0x0F00) >> 8);   offset++;
                    memory[offset] = 0x00 + (result & 0x00FF);          offset++;
                    // Read the next line
                    continue;
            }

            // JP ADDR - 1NNN
            if(arguments[0] == "JP")
            {
                    unsigned short result = 0x0000;
                    // Try to convert the second argument into an address
                    // If that fails, process the second argument as a label reference
                    if(!strTo12Bit(arguments[1], result))
                    {
                            // Create a new label reference
                            lref myLref = lref(arguments[1], offset);

                            // Make sure no array overflow will occur
                            if(num_lrefs >= list_lrefs_size)
                            {
                                    // Return an error message
                                    eflag = error(i_file, lineNumber, "Assembler error. Label reference array overflow. Maximum number of label references reached.");
                                    // Exit the program
                                    return false;
                            }

                            // Add the current label to the list for storage
                            list_lrefs[num_lrefs] = myLref;
                            num_lrefs++;
                    }

                    // Add corresponding machine code to memory
                    memory[offset] = 0x10 + ((result & 0x0F00) >> 8);   offset++;
                    memory[offset] = 0x00 + (result & 0x00FF);          offset++;
                    // Read the next line
                    continue;
            }

            // CALL ADDR - 2NNN
            if(arguments[0] == "CALL")
            {
                    unsigned short result = 0x0000;
                    // Try to convert the second argument into an address
                    // If that fails, process the second argument as a label reference
                    if(!strTo12Bit(arguments[1], result))
                    {
                            // Create a new label reference
                            lref myLref = lref(arguments[1], offset);

                            // Make sure no array overflow will occur
                            if(num_lrefs >= list_lrefs_size)
                            {
                                    // Return an error message
                                    eflag = error(i_file, lineNumber, "Assembler error. Label reference array overflow. Maximum number of label references reached.");
                                    // Exit the program
                                    return false;
                            }

                            // Add the current label to the list for storage
                            list_lrefs[num_lrefs] = myLref;
                            num_lrefs++;
                    }

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                    // Add corresponding machine code to memory
                    memory[offset] = 0x20 + ((result & 0x0F00) >> 8);   offset++;
                    memory[offset] = 0x00 + (result & 0x00FF);          offset++;
                    // Read the next line
                    continue;
                }

                // SKP VX - EX9E
                if(arguments[0] == "SKP")
                {
                    unsigned char byte = 0x00;
                    // Try to convert the second argument into a register
                    if(!strToRegister(arguments[1], byte))
                    {
                        // Unknown register
                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                        // Read the next line
                        continue;
                    }

                    // Add corresponding machine code to memory
                    memory[offset] = 0xE0 + byte; offset++;
                    memory[offset] = 0x9E;        offset++;
                    // Read the next line
                    continue;
                }

                // SKNP VX - EXA1
                if(arguments[0] == "SKNP")
                {
                    unsigned char byte = 0x00;
                    // Try to convert the second argument into a register
                    if(!strToRegister(arguments[1], byte))
                    {
                        // Unknown register
                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                        // Read the next line
                        continue;
                    }

                    // Add corresponding machine code to memory
                    memory[offset] = 0xE0 + byte; offset++;
                    memory[offset] = 0xA1;        offset++;
                    // Read the next line
                    continue;
                }

                // SHR VX - 8XY6
                if(arguments[0] == "SHR")
                {
                    unsigned char byte = 0x00;
                    // Try to convert the second argument into a register
                    if(!strToRegister(arguments[1], byte))
                    {
                        // Unknown register
                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                        // Read the next line
                        continue;
                    }

                    // Add corresponding machine code to memory
                    memory[offset] = 0x80 + byte;        offset++;
                    memory[offset] = 0x06 + (byte << 4); offset++;
                    // Read the next line
                    continue;
                }
```

```

            // SHL VX - 8XYE
            if(arguments[0] == "SHL")
            {
                unsigned char byte = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                // Add corresponding machine code to memory
                memory[offset] = 0x80 + byte;        offset++;
                memory[offset] = 0x0E + (byte << 4); offset++;
                // Read the next line
                continue;
            }

            // Unknown command
            eflag = error(i_file, lineNumber, "Syntax error. Unknown command \"" + arguments[0] + " " + arguments[1] + "\".");
            // Read the next line
            continue;
        }

        // Process all triple argument commands
        if(numArgs == 3)
        {
            // SE VX, BYTE - 3XKK
            // SE VX, VY   - 5XY0
            if(arguments[0] == "SE")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a byte
                if(strToByte(arguments[2], byte2))
                {
                    byte1 += 0x30;
                }
                // Try to convert the third argument into a register
                else if(strToRegister(arguments[2], byte2))
                {
                    byte1 += 0x50;
                    byte2 = byte2 << 4;
                }
                else
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                // Add corresponding machine code to memory
                memory[offset] = byte1;       offset++;
                memory[offset] = byte2;       offset++;
                // Read the next line
                continue;
            }

            // SNE VX, BYTE        - 4XKK
            // SNE VX, VY  - 9XY0
            if(arguments[0] == "SNE")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a byte
                if(strToByte(arguments[2], byte2))
                {
                    byte1 += 0x40;
                }
                // Try to convert the third argument into a register
                else if(strToRegister(arguments[2], byte2))
                {
                    byte1 += 0x90;
                    byte2 = byte2 << 4;
                }
                else
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                // Add corresponding machine code to memory
                memory[offset] = byte1;       offset++;
                memory[offset] = byte2;       offset++;
                // Read the next line
                continue;
            }

            // ADD VX, BYTE        - 7XKK
            // ADD VX, VY  - 8XY4
            if(arguments[0] == "ADD" && arguments[1] != "I")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a byte
                if(strToByte(arguments[2], byte2))
                {
                    byte1 += 0x70;
                }
                // Try to convert the third argument into a register
                else if(strToRegister(arguments[2], byte2))
                {
```

```
                                        byte1 += 0x80;
                                        byte2 = (byte2 << 4) + 0x04;
                                }
                                else
                                {
                                        // Invalid argument
                                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\".");
                                        // Read the next line
                                        continue;
                                }

                                // Add corresponding machine code to memory
                                memory[offset] = byte1;       offset++;
                                memory[offset] = byte2;       offset++;
                                // Read the next line
                                continue;
                        }

                        // ADD I, VX - FX1E
                        if(arguments[0] == "ADD" && arguments[1] == "I")
                        {
                                unsigned char byte = 0x00;
                                // Try to convert the third argument into a register
                                if(!strToRegister(arguments[2], byte))
                                {
                                        // Unknown register
                                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                                        // Read the next line
                                        continue;
                                }

                                // Add corresponding machine code to memory
                                memory[offset] = 0xF0 + byte; offset++;
                                memory[offset] = 0x1E;        offset++;
                                // Read the next line
                                continue;
                        }

                        // RND VX, BYTE - CXKK
                        if(arguments[0] == "RND")
                        {
                                unsigned char byte1 = 0x00;
                                // Try to convert the second argument into a register
                                if(!strToRegister(arguments[1], byte1))
                                {
                                        // Unknown register
                                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                                        // Read the next line
                                        continue;
                                }

                                unsigned char byte2 = 0x00;
                                // Try to convert the third argument into a byte
                                if(!strToByte(arguments[2], byte2))
                                {
                                        // Invalid argument
                                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\". Expected an 8-bit number.");
                                        // Read the next line
                                        continue;
                                }

                                // Add corresponding machine code to memory
                                memory[offset] = 0xC0 + byte1;       offset++;
                                memory[offset] = byte2;              offset++;
                                // Read the next line
                                continue;
                        }
```

```

            // OR  VX, VY - 8XY1
            // AND VX, VY - 8XY2
            // XOR VX, VY - 8XY3
            if(arguments[0] == "OR" || arguments[0] == "AND" || arguments[0] == "XOR")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a register
                if(!strToRegister(arguments[2], byte2))
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                // Shift byte2 left by four bits
                byte2 = byte2 << 4;

                // Determine what number to end the command with
                if(arguments[0] == "OR")
                    byte2 += 0x01;
                if(arguments[0] == "AND")
                    byte2 += 0x02;
                if(arguments[0] == "XOR")
                    byte2 += 0x03;

                // Add corresponding machine code to memory
                memory[offset] = 0x80 + byte1;      offset++;
                memory[offset] = byte2;             offset++;
                // Read the next line
                continue;
            }

            // SUB VX, VY - 8XY5
            if(arguments[0] == "SUB")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a register
                if(!strToRegister(arguments[2], byte2))
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                // Shift byte2 left by four bits
                byte2 = byte2 << 4;

                // Add corresponding machine code to memory
                memory[offset] = 0x80 + byte1;      offset++;
                memory[offset] = byte2 + 0x05;      offset++;
                // Read the next line
                continue;
            }

            // SUBN VX, VY - 8XY7
            if(arguments[0] == "SUBN")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a register
                if(!strToRegister(arguments[2], byte2))
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                // Shift byte2 left by four bits
                byte2 = byte2 << 4;

                // Add corresponding machine code to memory
                memory[offset] = 0x80 + byte1;      offset++;
                memory[offset] = byte2 + 0x07;      offset++;
                // Read the next line
                continue;
            }

            // SHR VX, VY - 8XY6
            if(arguments[0] == "SHR")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a register
                if(!strToRegister(arguments[2], byte2))
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

```

```
                                // Shift byte2 left by four bits
                                byte2 = byte2 << 4;

                                // Add corresponding machine code to memory
                                memory[offset] = 0x80 + byte1;          offset++;
                                memory[offset] = byte2 + 0x06;          offset++;
                                // Read the next line
                                continue;
                        }

                        // SHL VX, VY - 8XYE
                        if(arguments[0] == "SHL")
                        {
                                unsigned char byte1 = 0x00;
                                // Try to convert the second argument into a register
                                if(!strToRegister(arguments[1], byte1))
                                {
                                        // Unknown register
                                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                                        // Read the next line
                                        continue;
                                }

                                unsigned char byte2 = 0x00;
                                // Try to convert the third argument into a register
                                if(!strToRegister(arguments[2], byte2))
                                {
                                        // Invalid argument
                                        eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                                        // Read the next line
                                        continue;
                                }

                                // Shift byte2 left by four bits
                                byte2 = byte2 << 4;

                                // Add corresponding machine code to memory
                                memory[offset] = 0x80 + byte1;          offset++;
                                memory[offset] = byte2 + 0x0E;          offset++;
                                // Read the next line
                                continue;
                        }

                        // JP V0, ADDR - BNNN
                        if(arguments[0] == "JP")
                        {
                                // Make sure the second argument is the correct register
                                if(arguments[1] != "V0")
                                {
                                        // Unknown register
                                        eflag = error(i_file, lineNumber, "Syntax error. Invalid register \"" + arguments[1] + "\". Expected V0.");
                                        // Read the next line
                                        continue;
                                }

                                unsigned short result = 0x0000;
                                // Try to convert the third argument into an address
                                // If that fails, process the third argument as a label reference
                                if(!strTo12Bit(arguments[2], result))
                                {
                                        // Create a new label reference
                                        lref myLref = lref(arguments[2], offset);

                                        // Make sure no array overflow will occur
                                        if(num_lrefs >= list_lrefs_size)
                                        {
                                                // Return an error message
                        eflag = error(i_file, lineNumber, "Assembler error. Label reference array overflow. Maximum number of label references reached.");
                        // Exit the program
                        return false;
                    }

                    // Add the current label to the list for storage
                    list_lrefs[num_lrefs] = myLref;
                    num_lrefs++;
                }

                // Add corresponding machine code to memory
                memory[offset] = 0xB0 + ((result & 0x0F00) >> 8);   offset++;
                memory[offset] = 0x00 + (result & 0x00FF);          offset++;
                // Read the next line
                continue;
            }

            // LD VX,  BYTE        - 6XKK
            // LD I,   ADDR        - ANNN
            // LD VX,  DT  - FX07
            // LD VX,  K   - FX0A
            // LD VX,  [I] - FX65
            // LD VX,  VY  - 8XY0
            // LD DT,  VX  - FX15
            // LD ST,  VX  - FX18
            // LD F,   VX  - FX29
            // LD B,   VX  - FX33
            // LD [I], VX  - FX55
            if(arguments[0] == "LD")
            {
                unsigned char byte1 = 0x00;
                unsigned char byte2 = 0x00;

                // Try to convert the third argument into a register
                if(strToRegister(arguments[2], byte2))
                {
                    // Try to convert the second argument into a register
                    if(strToRegister(arguments[1], byte1))
                    {
                        byte1 += 0x80;

                        // Shift byte 2 left by four bits
                        byte2 = byte2 << 4;
                    }
                    else if(arguments[1] == "DT")
                    {
                        byte1 += 0xF0 + byte2;
                        byte2 = 0x15;
                    }
                    else if(arguments[1] == "ST")
                    {
                        byte1 += 0xF0 + byte2;
                        byte2 = 0x18;
                    }
                    else if(arguments[1] == "F")
                    {
                        byte1 += 0xF0 + byte2;
                        byte2 = 0x29;
                    }
                    else if(arguments[1] == "B")
                    {
                        byte1 += 0xF0 + byte2;
                        byte2 = 0x33;
                    }
                    else if(arguments[1] == "[I]")
                    {
                        byte1 += 0xF0 + byte2;
                        byte2 = 0x55;
                    }
                    else
                    {
                        // Invalid argument
                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[1] + "\".");
                        // Read the next line
                        continue;
                    }
                }

                // Try to convert the second argument into a register
                else if(strToRegister(arguments[1], byte1))
                {
                    unsigned short result = 0x0000;

                    // Try to convert the third argument into a byte
                    if(strToByte(arguments[2], byte2))
                    {
                        byte1 += 0x60;
                    }
                    else if(arguments[2] == "DT")
                    {
                        byte1 += 0xF0;
                        byte2 = 0x07;
                    }
                    else if(arguments[2] == "K")
                    {
                        byte1 += 0xF0;
                        byte2 = 0x0A;
                    }
                    else if(arguments[2] == "[I]")
                    {
                        byte1 += 0xF0;
                        byte2 = 0x65;
                    }
                    else
                    {
                        // Invalid argument
                        eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[2] + "\".");
                        // Read the next line
                        continue;
                    }
                }

                else if(arguments[1] == "I")
                {
                    unsigned short result = 0x0000;
                    // Try to convert the third argument into an address
                    // If that fails, process the third argument as a label reference
                    if(!strTo12Bit(arguments[2], result))
                    {
                        // Create a new label reference
                        lref myLref = lref(arguments[2], offset);

                        // Make sure no array overflow will occur
                        if(num_lrefs >= list_lrefs_size)
                        {
                            // Return an error message
                            eflag = error(i_file, lineNumber, "Assembler error. Label reference array overflow. Maximum number of label references reached.");
                            // Exit the program
                            return false;
                        }

                        // Add the current label to the list for storage
                        list_lrefs[num_lrefs] = myLref;
                        num_lrefs++;
                    }

                    byte1 = 0xA0 + ((result & 0x0F00) >> 8);
                    byte2 = 0x00 + (result & 0x00FF);
                }

                // Unknown command
                else
                {
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown command \"" + arguments[0] + " " + arguments[1] + ", " + arguments[2] + "\".");
                }

                // Add corresponding machine code to memory
                memory[offset] = byte1;       offset++;
                memory[offset] = byte2;       offset++;
                // Read the next line
                continue;
            }

            // Unknown command
            eflag = error(i_file, lineNumber, "Syntax error. Unknown command \"" + arguments[0] + " " + arguments[1] + ", " + arguments[2] + "\".");
            // Read the next line
            continue;
        }

        // Process all quadruple argument commands
        if(numArgs == 4)
        {
            // DRW VX, VY, NIBBLE - DXYN
            if(arguments[0] == "DRW")
            {
                unsigned char byte1 = 0x00;
                // Try to convert the second argument into a register
                if(!strToRegister(arguments[1], byte1))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[1] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char byte2 = 0x00;
                // Try to convert the third argument into a register
                if(!strToRegister(arguments[2], byte2))
                {
                    // Unknown register
                    eflag = error(i_file, lineNumber, "Syntax error. Unknown register \"" + arguments[2] + "\".");
                    // Read the next line
                    continue;
                }

                unsigned char nibble = 0x00;
                // Try to convert the third argument into a nibble
                if(!strToNibble(arguments[3], nibble))
                {
                    // Invalid argument
                    eflag = error(i_file, lineNumber, "Syntax error. Invalid argument \"" + arguments[3] + "\". Expected a 4-bit number.");
                    // Read the next line
                    continue;
                }

                // Add corresponding machine code to memory
                memory[offset] = 0xD0 + byte1;              offset++;
                memory[offset] = (byte2 << 4) + nibble;     offset++;
                // Read the next line
                continue;
```

```
                                }

                                // Unknown command
                                eflag = error(i_file, lineNumber, "Syntax error. Unknown command \"" + arguments[0] + " " + arguments[1] + ", " + arguments[2] + ", " + arguments[3] + "\".");
                                // Read the next line
                                continue;
                        }
                }
        }

        // ******************************************
        // Begin linking label references with labels
        // ******************************************

        // Loop through the array of label references
        for(unsigned char i_lref; i_lref < num_lrefs; i_lref++)
        {
                // The current label reference
                lref current_lref = list_lrefs[i_lref];

                // Locate the label being referenced by this label reference
                bool found = false;
                unsigned char i_label;
                for(i_label = 0; i_label < num_labels; i_label++)
                {
                        if(current_lref.getName() == list_labels[i_label].getName())
                        {
                                found = true;
                                break;
                        }
                }

                // If it is not found, output an error
                if(!found)
                {
                        // Output an error
                        eflag = error(i_file, 0, "Label error. Label \"" + current_lref.getName() + "\" not found.");
                        // Exit the program
                        return false;
                }

                // The current label
                label current_label = list_labels[i_label];

                // Jump to the offset address given by the label reference and insert the address designated by the corresponding label
                memory[current_lref.getAddress()]       += ((current_label.getAddress() + start) & 0x0F00) >> 8;
                memory[current_lref.getAddress() + 1]   += ((current_label.getAddress() + start) & 0x00FF);
        }

        // Close the source file
        source.close();

        // *****************************************
        // Output all CHIP-8 code to the output file
        // *****************************************

        // Has an error occured?
        if(!eflag)
        {
                // Open the output file for writing
                ofstream output;
                output.open(o_file.c_str(), ofstream::out);

                // Check if the output file has not been opened correctly
                if(!output.is_open())
                {
                        // Return an error message
                        error(o_file, 0, "File error. Could not open file \"" + o_file + "\" for output.");
                        // Exit the program
                        return false;
                }
                // Output all the generated machine code to the file
                for(unsigned int current_byte = 0; current_byte < offset; current_byte++)
                {
                        output << memory[current_byte];
                }

                // Close the output file
                output.close();
        }

        // ++++++++++++++++++++++++++++++++++++++++++++
        // Enable the following lines of code to output
        // all generated machine code to the screen++++
        // ++++++++++++++++++++++++++++++++++++++++++++
        /*
        cout << "###################" << endl;
        cout << "Machine Code Output" << endl;
        cout << "###################" << endl;

        if(offset > 0) {
        for(unsigned int z = 0; z < offset - 1; z += 2)
                printf ("#%03X \t %02X %02X \n", z + start, memory[z], memory[z+1]);
        }
        */

        return 0;
      }
```

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