### Getting Started

1) Configurations

- Open up Main.cpp. At the top of the file, there should be two #define directives, FFT and TESTS.

- To enable tests BEFORE executing the program, uncomment #define TESTS.

- Note that tests will delay the execution of the program by at least a minute

- To use the algorithm based optimization, FFT Convolution, uncomment #define FFT

2) Compilation

g++ \*.cpp –o a4 (or g++-4 \*.cpp –o a4 for 64-bit Windows Cygwin users)

3) Execution

./a4 (or a4 for Windows users)

### What Works

* Baseline Program (on .wav files)
* Algorithm-Based Optimization version of Baseline (on .wav files)
* Bonus #1: Stereo detection on Impulse Response (on .wav files)

### What Doesn’t Work

* Bonus #2: Handle aiff and snd file formats
* Using a snd file as any input or output file will produce a file that CAN be opened, but does not sound correct.
* Only a wave input / snd impulse / wav output, sounds close, but still not correct.
* I narrowed the reason down to reading the SND file data. Everything else works because I tried creating an SND file with WAVE data and it works. Therefore I’m reading the SND file data incorrectly, but I’m not sure why what I have is wrong.
* Using an aiff file as any input or output file will either produce (1) a file that CANNOT be opened (only tested with Windows Media Player) or (2) an openable file that has incorrect sounding output.
* I didn’t have much time to test this further, so I’m not sure why it doesn’t work.
* It may have to do with the fact that I just made a barebones AIFF file (all chunks except Common and Sound Data are optional, see References [5]). I tested opening the sound files with Windows Media Player, and it may have relied on these extra chunks.
* NOTE: I used sox to convert the dry recording and impulse responses from wave to snd and aiff. It is possible that I used sox incorrectly (maybe I didn’t set endian, b, c, or r flags correctly, or maybe more flags needed to be set) and that may have contributed to my strange outputs.

### Testing

* Unit tests are provided. four1 FFT and IFFT, and convolve/fftConvolve wrappers that take SoundFile\* are more difficult to test, and they are not tested directly.
* However, these convolve/fftConvolve wrappers are wrapping convolve/fftConvolve methods that take double\* signals. These lower level methods *are* tested.
* Four1 is indirectly tested through the regression test.
* The main regression test is found in RegressionTest.cpp and compares the output of the baseline program, with the algorithm-based optimization version of the baseline program (i.e. using FFT convolution).
* All tests were run after every optimization.

**Testing Constants and Inputs**

* Dry Recording: **testCase1.wav** – Mono 16-bit Sample Size
* Impulse Response: **Parking Garage.wav** – Mono 16-bit Sample Size

### Profiling

**Tool:** Microsoft Visual Studio Profiling Tools (see References [0])

**Measurement:** *Elapsed Inclusive* (for the whole program, see References [1]). This includes function stack set up and tear downs and system calls. Tests are turned off before profiling so tests are not included.

### Optimizations Performed

**Template**

**Code Before** **Code After**

<CODE BEFORE> <CODE AFTER>

**Steps**

1. The first step is always committing to version control, so they are not listed below.
2. The last step is always running tests, and it they pass, committing to version control, and profiling.

**Total Time Before:**

**Total Time After:**

These times are measured as *Elapsed Inclusive* in the scope of the entire program (i.e. main()). This means that the total time that is spent executing the *program* from start to finish is measured. This includes function stack set up and tear downs, as well as system calls. Tests are turned off before profiling so tests are not measured.

**Speed Gain:**

**Results So Far:**

This shows the trending total execution time of the program thus far. Ideally, as this table grows, the execution time as it grows.

\*\* NOTE \*\*

The total time before any optimizations (i.e. the total time of the baseline program) is **359525.44 ms**

**Algorithm Based Optimization – FFT Convolution**

**Code Before** **Code After**

int main(int argc, char\* argv[]) {

// dry is input signal, ir is impulse

Convolver::fftConvolve(dryNormalized,

dry->getDataSize(),

irNormalized,

ir->getDataSize(),

result, P);

. . .

}

}

int main(int argc, char\* argv[]) {

// dry is input signal, ir is impulse

Convolver::convolve(dryNormalized,

dry->getDataSize(),

irNormalized,

ir->getDataSize(),

result, P);

. . .

}

}

\* See Convolver.cpp for convolve() \* See Convolver.cpp for fftConvolve()

**Steps**

1. Make fftConvolve() for the optimized algorithm with the same arguments/signatures as convolve()
2. Convert input signals to frequency domain before applying convolution
3. Convert results back to time domain

Step 2 is where the magic happens. Only one linear loop, rather than a nested loop, through the signal for complex multiplication is required. O(N) is better than O(N\*M).

**Total Time Before:** 359,525.44 ms

**Total Time After:** 9,184.23 ms

**Speed Gain:** 350,341.21 ms

**Results So Far:**

|  |  |
| --- | --- |
| **Optimization Technique** | **Total Execution Time (ms)** |
| None | 359,525.44 |
| FFT Convolution | 9,184.23 |

**Code Tuning 1 – Eliminate Common Subexpressions**

**Code Before** **Code After**

void Convolver::zeroPadAndTimeToFreqDomain(…) {

int i = 0;

int i2;

for (; i < timeDomainLen; i++ ) {

i2 = i\*2;

outputFreqDomain[i2] = timeDomain[i];

outputFreqDomain[i2+1] = 0;

}

for (; i < structuredSize; i++ ) {

i2 = i\*2;

outputFreqDomain[i2] = 0;

outputFreqDomain[i2+1] = 0;

}

}

void Convolver::fftConvolve(…) {

int structuredSize = X;

int structuredSize2 = structuredSize\*2;

//Replace all structuredSize\*2 with structuredSize2

}

int main(int argc, char\* argv[]) {

int halfM = ir->getDataSize()/2;

// Replace all ir->getDataSize()/2 with halfM

}

void Convolver::zeroPadAndTimeToFreqDomain(…)

{

int i = 0;

for (; i < timeDomainLen; i++ ) {

outputFreqDomain[i\*2] = timeDomain[i];

outputFreqDomain[i\*2+1] = 0;

}

for (; i < structuredSize; i++ ) {

outputFreqDomain[i\*2] = 0;

outputFreqDomain[i\*2+1] = 0;

}

}

void Convolver::fftConvolve(…) {

int structuredSize = X; // X is some value

// Many occurences of structuredSize\*2

}

int main(int argc, char\* argv[]) {

// Many occurences of ir->getDataSize()/2

}

**Steps**

**Steps**

1. Find all values that are being repeatedly calculated (in this case, the loop counter i, the size of impulse response, and the structuredSize value is always being doubled or halved.
2. Calculate these values once, store them, and just use that pre-calculated value instead of recalculating.

**Total Time Before:** 9,184.23 ms

**Total Time After:** 8,792.83 ms

**Speed Gain:** 391.4 ms

**Results So Far:**

|  |  |
| --- | --- |
| **Optimization Technique** | **Total Execution Time (ms)** |
| None | 359,525.44 |
| FFT Convolution | 9,184.23 |
| Eliminate Common Subexpressions | 8,792.83 |

**Code Tuning 2 – Strength Reduction**

**Code Before** **Code After**

// Replace all occurrences of a multiplication or a division by 2 with bit shifting (i.e. use << to multiply or >> to divide)

// Many occurrences of a multiplication or a division by 2

**Steps**

1. Find all occurrences where there is a multiplication or a division by N where N is a power of 2.
2. Replace multiplication by N with shifting left floor(sqrt(N)) times
3. Replace division by N with shifting right floor(sqrt(N)) times

**Total Time Before:** 8,792.83 ms

**Total Time After:** 8,553.74 ms

**Speed Gain:**  239.09 ms

**Results So Far:**

|  |  |
| --- | --- |
| **Optimization Technique** | **Total Execution Time (ms)** |
| None | 359,525.44 |
| FFT Convolution | 9,184.23 |
| Eliminate Common Subexpressions | 8,792.83 |
| Strength Reduction | 8,553.74 |

**Code Tuning 3 – Minimize References** (Dereferencing a pointer or indexing an array)

**Code Before** **Code After**

int main(int argc, char\* argv[]) {

// dry is an object containing the dry recording

// ir is an object containing the impulse response

// Many occurences of:

dry->getData();

dry->getDataSize();

ir->getData();

ir->getDataSize();

. . .

}

int main(int argc, char\* argv[]) {

// dry is an object containing the dry recording

// ir is an object containing the impulse response

short\* dryData = dry->getData();

short\* irData = ir->getData();

int dryDataSize = dry->getDataSize();

int irDataSize = ir->getDataSize();

// Use above cached values rather than dereferencing dry and ir every time

}

**Steps**

**Steps**

1. Make local variables containing the values that are often obtained through dereferencing some pointer
2. Use these local variables rather than dereferencing
3. There are no assignments through dereferencing in this case, so we don’t have to worry about that

**Total Time Before:** 8,553.74 ms

**Total Time After:** 8,277.55 ms

**Speed Gain:** 276.19 ms

**Results So Far:**

|  |  |
| --- | --- |
| **Optimization Technique** | **Total Execution Time (ms)** |
| None | 359,525.44 |
| FFT Convolution | 9,184.23 |
| Eliminate Common Subexpressions | 8,792.83 |
| Strength Reduction | 8,553.74 |
| Minimize References | 8,277.55 |

**Code Tuning 4 – Macro Convolver::normalize**

**Code Before** **Code After**

**Steps**

**Steps**

**Total Time Before:**

**Total Time After:**

**Speed Gain:**

**Results So Far:**

**Code Tuning 5 – Jamming (DO MIN\_ELEMENT STUFF TOO)**

**Code Before** **Code After**

**Steps**

**Steps**

**Total Time Before:**

**Total Time After:**

**Speed Gain:**

**Results So Far:**

**Code Tuning 6 – Partial Unrolling**

**Code Before** **Code After**

**Steps**

**Steps**

**Total Time Before:**

**Total Time After:**

**Speed Gain:**

**Results So Far:**

### References

Microsoft Visual Studio Profiling Tools: [0] <http://msdn.microsoft.com/en-us/library/z9z62c29.aspx>

Documentation: [1] <http://msdn.microsoft.com/en-us/library/dd264994.aspx>

Snd File Format:

[2] <http://sox.sourceforge.net/AudioFormats-11.html>

[3] <http://en.wikipedia.org/wiki/Au_file_format>

[4] <http://www-mmsp.ece.mcgill.ca/documents/audioformats/AU/AU.html>

Aiff File Format:

[5] <http://www-mmsp.ece.mcgill.ca/Documents/AudioFormats/AIFF/Docs/AIFF-1.3.pdf>

[6] <http://muratnkonar.com/aiff/index.html>

Leonard Manzara & Abbas Sarraf : Amazing and helpful professor and TA.