Yunfan Yang 30067857

<https://gitlab.cpsc.ucalgary.ca/yunfan.yang/cpsc-501-assignment-2/>

The access to this repository has been granted to the TA and the professor.

Graphical user interface, text, application, email

Description automatically generated

# Baseline Program

Commit: 8f6c17866033a1326ec17acbe77a0a517f328efa

This is the baseline version of the program. It implements: read and write wave file, convolution with O(n^2) time complexity multiplication algorithm.

The full audio takes a really long time to convolute.

## Profiling

guitar\_dry.wav

% cumulative self self total

time seconds seconds calls s/call s/call name

100.00 407.87 407.87 1 **407.87** 407.87 convolution(WaveFile, WaveFile)

0.00 407.88 0.01 1 0.01 0.01 WaveFile::writeData()

0.00 407.88 0.00 12 0.00 0.00 WaveFile::nextIntLSB()

0.00 407.88 0.00 8 0.00 0.00 WaveFile::nextShortLSB()

0.00 407.88 0.00 5 0.00 0.00 WaveFile::nextIntLSB(int)

0.00 407.88 0.00 5 0.00 0.00 WaveFile::~WaveFile()

0.00 407.88 0.00 4 0.00 0.00 WaveFile::nextShortLSB(short)

0.00 407.88 0.00 3 0.00 0.00 WaveFile::WaveFile()

0.00 407.88 0.00 2 0.00 0.00 WaveFile::readHeader()

0.00 407.88 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 407.88 0.00 2 0.00 0.00 WaveFile::readData()

0.00 407.88 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 407.88 0.00 1 0.00 0.00 WaveFile::writeHeader()

0.00 407.88 0.00 1 0.00 0.01 WaveFile::write(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

Graphical user interface

Description automatically generated with medium confidence

This is a comparison graph of the provided sample output with the output from my program. The files are almost identical.

# Algorithmic Optimization: FFT Program

Commit: c9fc0d2c8a3854b44c11a52c5684a7c9c77c09c6

This is the optimized version of convolution algorithm, using Fast Fourier Transform to achieve O(n log n) time complexity.

The code is partially referenced from: [Fast Fourier transform - Rosetta Code](https://rosettacode.org/wiki/Fast_Fourier_transform#C.2B.2B).

It implements: find the next closest n^2 number, fft and ifft, updated convolution function adapted fft and ifft.

The time is reduced from 407 seconds to 1.92 seconds, which is really significant.

## Profiling

guitar\_dry.wav

% cumulative self self total

time seconds seconds calls s/call s/call name

33.78 2.00 2.00 3 0.67 **1.92** fft(std::valarray<std::complex<double> >&)

8.78 2.52 0.52 134217728 0.00 0.00 std::complex<double>& std::complex<double>::operator\*=<double>(std::complex<double> const&)

8.45 3.02 0.50 136314884 0.00 0.00 std::complex<double>::complex(double, double)

7.60 3.47 0.45 132120576 0.00 0.00 std::complex<double> std::polar<double>(double const&, double const&)

5.24 3.78 0.31 274505830 0.00 0.00 std::complex<double>::real[abi:cxx11]() const

4.56 4.05 0.27 12582906 0.00 0.00 void std::\_\_valarray\_copy\_construct<std::complex<double> >(std::complex<double> const\*, unsigned int, unsigned int, std::complex<double>\*)

4.05 4.29 0.24 400113869 0.00 0.00 std::valarray<std::complex<double> >::operator[](unsigned int)

3.89 4.52 0.23 272629760 0.00 0.00 std::complex<double>::imag[abi:cxx11]() const

3.38 4.72 0.20 66060288 0.00 0.00 std::complex<double> std::operator-<double>(std::complex<double> const&, std::complex<double> const&)

2.87 4.89 0.17 66060288 0.00 0.00 std::complex<double> std::operator+<double>(std::complex<double> const&, std::complex<double> const&)

2.70 5.05 0.16 66060288 0.00 0.00 std::complex<double>& std::complex<double>::operator-=<double>(std::complex<double> const&)

2.53 5.20 0.15 134217728 0.00 0.00 std::complex<double> std::operator\*<double>(std::complex<double> const&, std::complex<double> const&)

1.86 5.31 0.11 12582912 0.00 0.00 void std::\_\_valarray\_destroy\_elements<std::complex<double> >(std::complex<double>\*, std::complex<double>\*)

1.52 5.40 0.09 66060288 0.00 0.00 std::complex<double>& std::complex<double>::operator+=<double>(std::complex<double> const&)

1.18 5.47 0.07 37748722 0.00 0.00 std::\_Array<std::complex<double> >::\_Array(std::complex<double>\*)

1.01 5.53 0.06 138412032 0.00 0.00 operator new(unsigned int, void\*)

0.84 5.58 0.05 12582906 0.00 0.00 std::slice\_array<std::complex<double> >::slice\_array(std::\_Array<std::complex<double> >, std::slice const&)

0.84 5.63 0.05 12582906 0.00 0.00 std::valarray<std::complex<double> >::operator[](std::slice)

0.51 5.66 0.03 12582913 0.00 0.00 std::valarray<std::complex<double> >::size() const

0.51 5.69 0.03 12582906 0.00 0.00 std::slice::start() const

0.34 5.71 0.02 12582912 0.00 0.00 std::\_\_valarray\_release\_memory(void\*)

0.34 5.73 0.02 12582909 0.00 0.00 std::valarray<std::complex<double> >::~valarray()

0.34 5.75 0.02 12582909 0.00 0.00 std::complex<double>\* restrict std::\_\_valarray\_get\_storage<std::complex<double> >(unsigned int)

0.34 5.77 0.02 12582906 0.00 0.00 std::slice::size() const

0.34 5.79 0.02 12582906 0.00 0.00 std::slice::slice(unsigned int, unsigned int, unsigned int)

0.34 5.81 0.02 12582906 0.00 0.00 std::valarray<std::complex<double> >::valarray(std::slice\_array<std::complex<double> > const&)

0.34 5.83 0.02 2097152 0.00 0.00 std::complex<double>& std::complex<double>::operator/=<double>(std::complex<double> const&)

0.34 5.85 0.02 3 0.01 0.01 std::\_Array\_init\_ctor<std::complex<double>, false>::\_S\_do\_it(std::complex<double>\*, std::complex<double>\*, std::complex<double>)

0.34 5.87 0.02 2 0.01 0.02 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.17 5.88 0.01 1876071 0.00 0.00 std::complex<double>::operator=(double)

0.17 5.89 0.01 1 0.01 0.01 WaveFile::writeData()

0.17 5.90 0.01 1 0.01 0.02 void std::\_\_valarray\_copy<std::complex<double>, std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > >(std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.17 5.91 0.01 operator delete(void\*)

0.17 5.92 0.01 cos

0.00 5.92 0.00 12582909 0.00 0.00 std::\_\_valarray\_get\_memory(unsigned int)

0.00 5.92 0.00 12582906 0.00 0.00 std::slice::stride() const

0.00 5.92 0.00 12582906 0.00 0.00 std::\_Array<std::complex<double> >::begin() const

0.00 5.92 0.00 12582906 0.00 0.00 void std::\_\_valarray\_copy\_construct<std::complex<double> >(std::\_Array<std::complex<double> >, unsigned int, unsigned int, std::\_Array<std::complex<double> >)

0.00 5.92 0.00 8388608 0.00 0.00 std::valarray<std::complex<double> >::operator[](unsigned int) const

0.00 5.92 0.00 4194304 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::operator[](unsigned int) const

0.00 5.92 0.00 4194304 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::operator[](unsigned int) const

0.00 5.92 0.00 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

0.00 5.92 0.00 2097152 0.00 0.00 std::complex<double> std::\_\_multiplies::operator()<std::complex<double> >(std::complex<double> const&, std::complex<double> const&) const

0.00 5.92 0.00 2097152 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::operator[](unsigned int) const

0.00 5.92 0.00 2097152 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::operator[](unsigned int) const

0.00 5.92 0.00 12 0.00 0.00 WaveFile::nextIntLSB()

0.00 5.92 0.00 8 0.00 0.00 WaveFile::nextShortLSB()

0.00 5.92 0.00 5 0.00 0.00 WaveFile::nextIntLSB(int)

0.00 5.92 0.00 5 0.00 0.00 WaveFile::~WaveFile()

0.00 5.92 0.00 4 0.00 0.00 WaveFile::nextShortLSB(short)

0.00 5.92 0.00 3 0.00 0.00 WaveFile::WaveFile()

0.00 5.92 0.00 3 0.00 0.01 std::valarray<std::complex<double> >::resize(unsigned int, std::complex<double>)

0.00 5.92 0.00 3 0.00 0.00 std::valarray<std::complex<double> >::valarray()

0.00 5.92 0.00 3 0.00 0.01 void std::\_\_valarray\_fill\_construct<std::complex<double> >(std::complex<double>\*, std::complex<double>\*, std::complex<double>)

0.00 5.92 0.00 2 0.00 0.00 WaveFile::readHeader()

0.00 5.92 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 5.92 0.00 2 0.00 0.00 WaveFile::readData()

0.00 5.92 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 5.92 0.00 2 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::size() const

0.00 5.92 0.00 2 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::size() const

0.00 5.92 0.00 2 0.00 0.00 std::valarray<std::complex<double> >::apply(std::complex<double> (\*)(std::complex<double> const&)) const

0.00 5.92 0.00 2 0.00 0.00 std::\_RefFunClos<std::\_ValArray, std::complex<double> >::\_RefFunClos(std::valarray<std::complex<double> > const&, std::complex<double> (\*)(std::complex<double> const&))

0.00 5.92 0.00 2 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::\_Expr(std::\_RefFunClos<std::\_ValArray, std::complex<double> > const&)

0.00 5.92 0.00 2 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::\_FunBase(std::valarray<std::complex<double> > const&, std::complex<double> (\*)(std::complex<double> const&))

0.00 5.92 0.00 2 0.00 0.02 std::valarray<std::complex<double> >& std::valarray<std::complex<double> >::operator=<std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&)

0.00 5.92 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 5.92 0.00 1 0.00 0.00 upper\_power\_of\_two(unsigned long)

0.00 5.92 0.00 1 0.00 1.99 ifft(std::valarray<std::complex<double> >&)

0.00 5.92 0.00 1 0.00 0.00 WaveFile::writeHeader()

0.00 5.92 0.00 1 0.00 0.01 WaveFile::write(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 5.92 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::size() const

0.00 5.92 0.00 1 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::size() const

0.00 5.92 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::\_Expr(std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > const&)

0.00 5.92 0.00 1 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::\_BinBase(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

0.00 5.92 0.00 1 0.00 0.00 std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >::\_BinClos(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

0.00 5.92 0.00 1 0.00 0.02 std::valarray<std::complex<double> >& std::valarray<std::complex<double> >::operator=<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > >(std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> > const&)

0.00 5.92 0.00 1 0.00 0.02 std::valarray<std::complex<double> >::operator/=(std::complex<double> const&)

0.00 5.92 0.00 1 0.00 0.02 void std::\_Array\_augmented\_\_\_divides<std::complex<double> >(std::\_Array<std::complex<double> >, unsigned int, std::complex<double> const&)

0.00 5.92 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::\_\_fun<std::\_\_multiplies, std::complex<double> >::result\_type> std::operator\*<std::complex<double> >(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

As one can see, the function takes most of the time is fft, thus the following optimizations are focusing on reducing the time of this function.

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.

# Optimization: Compiler

Commit: 0678ecb72ed3a312b64431627424332c50eeace9

In the vscode build task configuration file, the optimization tag -O2 is added to compile. Then run the build task and run the program.

Text

Description automatically generated

## Profiling

% cumulative self self total

time seconds seconds calls s/call s/call name

33.05 1.94 1.94 3 0.65 **1.90** fft(std::valarray<std::complex<double> >&)

9.88 2.52 0.58 136314884 0.00 0.00 std::complex<double>::complex(double, double)

8.69 3.03 0.51 132120576 0.00 0.00 std::complex<double> std::polar<double>(double const&, double const&)

8.52 3.53 0.50 274505830 0.00 0.00 std::complex<double>::real[abi:cxx11]() const

6.47 3.91 0.38 134217728 0.00 0.00 std::complex<double>& std::complex<double>::operator\*=<double>(std::complex<double> const&)

5.62 4.24 0.33 400113869 0.00 0.00 std::valarray<std::complex<double> >::operator[](unsigned int)

4.26 4.49 0.25 12582906 0.00 0.00 void std::\_\_valarray\_copy\_construct<std::complex<double> >(std::complex<double> const\*, unsigned int, unsigned int, std::complex<double>\*)

3.75 4.71 0.22 272629760 0.00 0.00 std::complex<double>::imag[abi:cxx11]() const

2.90 4.88 0.17 12582912 0.00 0.00 void std::\_\_valarray\_destroy\_elements<std::complex<double> >(std::complex<double>\*, std::complex<double>\*)

2.73 5.04 0.16 66060288 0.00 0.00 std::complex<double> std::operator+<double>(std::complex<double> const&, std::complex<double> const&)

2.39 5.18 0.14 66060288 0.00 0.00 std::complex<double>& std::complex<double>::operator+=<double>(std::complex<double> const&)

2.21 5.31 0.13 134217728 0.00 0.00 std::complex<double> std::operator\*<double>(std::complex<double> const&, std::complex<double> const&)

1.87 5.42 0.11 66060288 0.00 0.00 std::complex<double>& std::complex<double>::operator-=<double>(std::complex<double> const&)

0.85 5.47 0.05 138412032 0.00 0.00 operator new(unsigned int, void\*)

0.85 5.52 0.05 66060288 0.00 0.00 std::complex<double> std::operator-<double>(std::complex<double> const&, std::complex<double> const&)

0.85 5.57 0.05 12582906 0.00 0.00 std::valarray<std::complex<double> >::valarray(std::slice\_array<std::complex<double> > const&)

0.68 5.61 0.04 12582909 0.00 0.00 std::\_\_valarray\_get\_memory(unsigned int)

0.51 5.64 0.03 12582906 0.00 0.00 std::slice::slice(unsigned int, unsigned int, unsigned int)

0.51 5.67 0.03 sin

0.34 5.69 0.02 37748722 0.00 0.00 std::\_Array<std::complex<double> >::\_Array(std::complex<double>\*)

0.34 5.71 0.02 12582909 0.00 0.00 std::valarray<std::complex<double> >::~valarray()

0.34 5.73 0.02 12582906 0.00 0.00 std::slice::size() const

0.34 5.75 0.02 12582906 0.00 0.00 std::slice\_array<std::complex<double> >::slice\_array(std::\_Array<std::complex<double> >, std::slice const&)

0.34 5.77 0.02 12582906 0.00 0.00 void std::\_\_valarray\_copy\_construct<std::complex<double> >(std::\_Array<std::complex<double> >, unsigned int, unsigned int, std::\_Array<std::complex<double> >)

0.34 5.79 0.02 2097152 0.00 0.00 std::complex<double>& std::complex<double>::operator/=<double>(std::complex<double> const&)

0.17 5.80 0.01 12582912 0.00 0.00 std::\_\_valarray\_release\_memory(void\*)

0.17 5.81 0.01 12582909 0.00 0.00 std::complex<double>\* restrict std::\_\_valarray\_get\_storage<std::complex<double> >(unsigned int)

0.17 5.82 0.01 12582906 0.00 0.00 std::\_Array<std::complex<double> >::begin() const

0.17 5.83 0.01 4194304 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::operator[](unsigned int) const

0.17 5.84 0.01 2097152 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::operator[](unsigned int) const

0.17 5.85 0.01 1 0.01 0.01 WaveFile::writeData()

0.17 5.86 0.01 operator delete(void\*)

0.17 5.87 0.01 cos

0.00 5.87 0.00 12582913 0.00 0.00 std::valarray<std::complex<double> >::size() const

0.00 5.87 0.00 12582906 0.00 0.00 std::slice::start() const

0.00 5.87 0.00 12582906 0.00 0.00 std::slice::stride() const

0.00 5.87 0.00 12582906 0.00 0.00 std::valarray<std::complex<double> >::operator[](std::slice)

0.00 5.87 0.00 8388608 0.00 0.00 std::valarray<std::complex<double> >::operator[](unsigned int) const

0.00 5.87 0.00 4194304 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::operator[](unsigned int) const

0.00 5.87 0.00 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

0.00 5.87 0.00 2097152 0.00 0.00 std::complex<double> std::\_\_multiplies::operator()<std::complex<double> >(std::complex<double> const&, std::complex<double> const&) const

0.00 5.87 0.00 2097152 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::operator[](unsigned int) const

0.00 5.87 0.00 1876071 0.00 0.00 std::complex<double>::operator=(double)

0.00 5.87 0.00 12 0.00 0.00 WaveFile::nextIntLSB()

0.00 5.87 0.00 8 0.00 0.00 WaveFile::nextShortLSB()

0.00 5.87 0.00 5 0.00 0.00 WaveFile::nextIntLSB(int)

0.00 5.87 0.00 5 0.00 0.00 WaveFile::~WaveFile()

0.00 5.87 0.00 4 0.00 0.00 WaveFile::nextShortLSB(short)

0.00 5.87 0.00 3 0.00 0.00 WaveFile::WaveFile()

0.00 5.87 0.00 3 0.00 0.00 std::\_Array\_init\_ctor<std::complex<double>, false>::\_S\_do\_it(std::complex<double>\*, std::complex<double>\*, std::complex<double>)

0.00 5.87 0.00 3 0.00 0.00 std::valarray<std::complex<double> >::resize(unsigned int, std::complex<double>)

0.00 5.87 0.00 3 0.00 0.00 std::valarray<std::complex<double> >::valarray()

0.00 5.87 0.00 3 0.00 0.00 void std::\_\_valarray\_fill\_construct<std::complex<double> >(std::complex<double>\*, std::complex<double>\*, std::complex<double>)

0.00 5.87 0.00 2 0.00 0.00 WaveFile::readHeader()

0.00 5.87 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 5.87 0.00 2 0.00 0.00 WaveFile::readData()

0.00 5.87 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 5.87 0.00 2 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::size() const

0.00 5.87 0.00 2 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::size() const

0.00 5.87 0.00 2 0.00 0.00 std::valarray<std::complex<double> >::apply(std::complex<double> (\*)(std::complex<double> const&)) const

0.00 5.87 0.00 2 0.00 0.00 std::\_RefFunClos<std::\_ValArray, std::complex<double> >::\_RefFunClos(std::valarray<std::complex<double> > const&, std::complex<double> (\*)(std::complex<double> const&))

0.00 5.87 0.00 2 0.00 0.00 std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> >::\_Expr(std::\_RefFunClos<std::\_ValArray, std::complex<double> > const&)

0.00 5.87 0.00 2 0.00 0.00 std::\_FunBase<std::valarray<std::complex<double> >, std::complex<double> const&>::\_FunBase(std::valarray<std::complex<double> > const&, std::complex<double> (\*)(std::complex<double> const&))

0.00 5.87 0.00 2 0.00 0.02 std::valarray<std::complex<double> >& std::valarray<std::complex<double> >::operator=<std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&)

0.00 5.87 0.00 2 0.00 0.02 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 5.87 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 5.87 0.00 1 0.00 0.00 upper\_power\_of\_two(unsigned long)

0.00 5.87 0.00 1 0.00 1.97 ifft(std::valarray<std::complex<double> >&)

0.00 5.87 0.00 1 0.00 0.00 WaveFile::writeHeader()

0.00 5.87 0.00 1 0.00 0.01 WaveFile::write(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 5.87 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::size() const

0.00 5.87 0.00 1 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::size() const

0.00 5.87 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> >::\_Expr(std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > const&)

0.00 5.87 0.00 1 0.00 0.00 std::\_BinBase<std::\_\_multiplies, std::valarray<std::complex<double> >, std::valarray<std::complex<double> > >::\_BinBase(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

0.00 5.87 0.00 1 0.00 0.00 std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >::\_BinClos(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

0.00 5.87 0.00 1 0.00 0.02 std::valarray<std::complex<double> >& std::valarray<std::complex<double> >::operator=<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > >(std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> > const&)

0.00 5.87 0.00 1 0.00 0.03 std::valarray<std::complex<double> >::operator/=(std::complex<double> const&)

0.00 5.87 0.00 1 0.00 0.02 void std::\_\_valarray\_copy<std::complex<double>, std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> > >(std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 5.87 0.00 1 0.00 0.03 void std::\_Array\_augmented\_\_\_divides<std::complex<double> >(std::\_Array<std::complex<double> >, unsigned int, std::complex<double> const&)

0.00 5.87 0.00 1 0.00 0.00 std::\_Expr<std::\_BinClos<std::\_\_multiplies, std::\_ValArray, std::\_ValArray, std::complex<double>, std::complex<double> >, std::\_\_fun<std::\_\_multiplies, std::complex<double> >::result\_type> std::operator\*<std::complex<double> >(std::valarray<std::complex<double> > const&, std::valarray<std::complex<double> > const&)

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.

# Optimization: Jamming

Commit: aa4af5687890fd17b5a094a3d7ab075670878715

This optimization combines the two for-loops from the fft function into one.

A screenshot of a computer

Description automatically generated with medium confidence

Now, the time has reduced from 1.9 seconds to 233.33 miliseconds, which is also a significant improvement.

## Profiling

% cumulative self self total

time seconds seconds calls ms/call ms/call name

88.61 0.70 0.70 3 **233.33** 233.33 fft(std::valarray<std::complex<double> >&)

5.06 0.74 0.04 \_\_muldc3

1.27 0.75 0.01 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

1.27 0.76 0.01 \_fu1\_\_\_ZSt4cout

1.27 0.77 0.01 \_fu21\_\_\_ZSt4cout

1.27 0.78 0.01 \_fu45\_\_\_ZSt4cout

1.27 0.79 0.01 \_fu9\_\_\_ZSt4cout

0.00 0.79 0.00 11 0.00 0.00 \_\_gcc\_deregister\_frame

0.00 0.79 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 0.79 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 0.79 0.00 2 0.00 5.00 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 0.79 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 0.79 0.00 1 0.00 243.33 ifft(std::valarray<std::complex<double> >&)

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.

# Optimization: Minimize Array Reference

Commit: f9735ee1628c4b48bd3e4da1237dc2ea05b226a9

This optimization replace all the even[k] reference with a variable, for fft function. Thus, the access to even[k] would only be once.

A screenshot of a computer

Description automatically generated with medium confidence

## Profiling

% cumulative self self total

time seconds seconds calls ms/call ms/call name

95.16 0.59 0.59 3 196.67 **196.67** fft(std::valarray<std::complex<doubsle> >&)

1.61 0.60 0.01 \_fu1\_\_\_ZSt4cout

1.61 0.61 0.01 \_fu21\_\_\_ZSt4cout

1.61 0.62 0.01 \_fu45\_\_\_ZSt4cout

0.00 0.62 0.00 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

0.00 0.62 0.00 11 0.00 0.00 \_\_gcc\_deregister\_frame

0.00 0.62 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 0.62 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 0.62 0.00 2 0.00 0.00 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 0.62 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 0.62 0.00 1 0.00 196.67 ifft(std::valarray<std::complex<double> >&)

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.

# Optimization: Minimize work

Commit: 6116b4d04ffb1d0cc66d1a1ce48df70e0cb4544d

This optimization replaces all n/2 with a variable, for fft function, so the program would not need to do division every time.

Text

Description automatically generated

## Profiling

% cumulative self self total

time seconds seconds calls ms/call ms/call name

90.38 0.47 0.47 3 156.67 **156.67** fft(std::valarray<std::complex<double> >&)

1.92 0.48 0.01 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

1.92 0.49 0.01 \_fu1\_\_\_ZSt4cout

1.92 0.50 0.01 \_fu45\_\_\_ZSt4cout

1.92 0.51 0.01 \_fu9\_\_\_ZSt4cout

1.92 0.52 0.01 sin

0.00 0.52 0.00 11 0.00 0.00 \_\_gcc\_deregister\_frame

0.00 0.52 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 0.52 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 0.52 0.00 2 0.00 5.00 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 0.52 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 0.52 0.00 1 0.00 166.67 ifft(std::valarray<std::complex<double> >&)

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.

# Optimization: Constant

Commit: 6006b3dcff99b3d7aa885a9a7c7d8a7ceea4963a

This optimization replace -2 \* PI with a defined constant, for fft function, so the program would not need to dynamically compute the value for each iteration of the for-loop in the runtime.

Text

Description automatically generated

## Profiling

% cumulative self self total

time seconds seconds calls ms/call ms/call name

87.23 0.41 0.41 3 136.67 **136.67** fft(std::valarray<std::complex<double> >&)

4.26 0.43 0.02 \_\_muldc3

2.13 0.44 0.01 \_fu1\_\_\_ZSt4cout

2.13 0.45 0.01 \_fu21\_\_\_ZSt4cout

2.13 0.46 0.01 \_fu45\_\_\_ZSt4cout

2.13 0.47 0.01 \_fu9\_\_\_ZSt4cout

0.00 0.47 0.00 4194304 0.00 0.00 std::complex<double> std::conj<double>(std::complex<double> const&)

0.00 0.47 0.00 11 0.00 0.00 \_\_gcc\_deregister\_frame

0.00 0.47 0.00 2 0.00 0.00 WaveFile::read(std::\_\_cxx11::basic\_string<char, std::char\_traits<char>, std::allocator<char> >)

0.00 0.47 0.00 2 0.00 0.00 WaveFile::WaveFile(WaveFile const&)

0.00 0.47 0.00 2 0.00 0.00 void std::\_\_valarray\_copy<std::complex<double>, std::\_RefFunClos<std::\_ValArray, std::complex<double> > >(std::\_Expr<std::\_RefFunClos<std::\_ValArray, std::complex<double> >, std::complex<double> > const&, unsigned int, std::\_Array<std::complex<double> >)

0.00 0.47 0.00 1 0.00 0.00 convolution(WaveFile, WaveFile)

0.00 0.47 0.00 1 0.00 136.67 ifft(std::valarray<std::complex<double> >&)

## Regression Testing

Text

Description automatically generated with medium confidence

To testing the correctness, compare the new output file with the original base version output file.

There is nothing prints after the compare command, which indicates that the two files are identical.