High Performance Computing

Homework #5: Extra Credit

Due: Wed Nov 17 2021 before 11:59 PM

Email-based help Cutoff: 5:00 PM on Tue, Nov 16 2021

!	**Note: Extra Credit**: Continue to build on Phase #2 performance (no, you cannot use the starter code or Phase #1 for this extra credit unless you chose not to submit anything for Phase #2) to further improve the performance. Yes, you may use OpenMP constructs.

Name: John Doll

Experimental Platform

The experiments documented in this report were conducted on the following platform:

Component	*Details*
CPU Model	Intel(R) Xeon(R) Gold 6148 CPU @ 2.40GHz
CPU/Core Speed	2.4Ghz
Operating system used	Linux pitzer-login04.hpc.osc.edu 3.10.0-1160.36.2.el7.x86_64 #1 SMP Thu Jul 8 02:53:40 UTC 2021 x86_64 x86_64 x86_64 GNU/Linux
Interconnect type & speed (if applicable)	Not applicable
Was machine dedicated to task (`yes`/`no`)	Yes (via a `slurm` job)
Name and version of C++ compiler (if used)	gcc version 8.4.0 (GCC)
Name and version of Java compiler (if used)	None
Name and version of other non-standard software tools & components (if used)	

Runtime data for the reference performance

In the table below, record the reference runtime characteristics. This is the data for your enhanced version from Phase #1:

Rep	User time (sec)	Elapsed time (sec)	Peak memory (KB)
1	27.20	27.74	3444
2	27.28	27.83	3444

3	27.04	27.51	3531
4	25.69	26.13	3440
5	25.63	26.13	3299

Perf report data for the reference implementation

In the space below, copy-paste the `perf` profile data that you used to identify the aspect/method to reimplement to improve performance:

```
--19.54%--loadPGM
          |        |        |
          |        |        |--13.09%--std::istream::operator>> (inlined)
          |        |        |        |
          |        |        |         --12.92%--std::istream::_M_extract<double>
          |        |        |                   |
          |        |        |                   |--10.77%--std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::get (inlined)
          |        |        |                   |        |
          |        |        |                   |         --10.41%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::do_get
          |        |        |                   |                  |
          |        |        |                   |                  |--3.05%--std::string::reserve
          |        |        |                   |                  |        |
          |        |        |                   |                  |         --2.69%--std::string::_Rep::_M_clone
          |        |        |                   |                  |                   |
          |        |        |                   |                  |                   --1.97%--std::string::_Rep::_S_create
          |        |        |                   |                  |                             |
          |        |        |                   |                  |                             --1.79%--
__gnu_cxx::new_allocator<char>::allocate (inlined)
          |        |        |                   |                  |                                       operator new
          |        |        |                   |                  |                                       __GI___libc_malloc
(inlined)
          |        |        |                   |                  |                                       |
          |        |        |                   |                  |                                       --0.89%--
_int_malloc
          |        |        |                   |                  |
          |        |        |                   |                  |--2.65%--std::__convert_to_v<double>
          |        |        |                   |                  |        |
          |        |        |                   |                  |         --2.47%--____strtod_l_internal (inlined)
          |        |        |                   |                  |
          |        |        |                   |                  |--2.54%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::_M_extract_float
          |        |        |                   |                  |        |
          |        |        |                   |                  |         --0.55%--std::operator!=<char,
std::char_traits<char> > (inlined)
```

```
          |       |       |               |               |               std::istreambuf_iterator<char,
std::char_traits<char> >::equal (inlined)
          |       |       |               |               |               std::istreambuf_iterator<char,
std::char_traits<char> >::_M_at_eof (inlined)
          |       |       |               |               |               std::istreambuf_iterator<char,
std::char_traits<char> >::_M_get (inlined)
          |       |       |               |               |
          |       |       |               |                   --1.44%--std::basic_string<char,
std::char_traits<char>, std::allocator<char> >::~basic_string (inlined)
          |       |       |               |                   std::string::_Rep::_M_dispose (inlined)
          |       |       |               |                    |
          |       |       |               |                     --1.09%--_int_free
          |       |       |               |
          |       |       |                --1.62%--std::istream::sentry::sentry
          |       |       |
          |       |       |--3.75%--Matrix::Matrix
          |       |       |           std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::vector (inlined)
          |       |       |           std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::_M_fill_initialize (inlined)
          |       |       |               std::__uninitialized_fill_n_a<std::vector<double,
std::allocator<double> >*, unsigned long, std::vector<double, std::allocator<double> >,
std::vector<double, std::allocator<double> > > (inlined)
          |       |       |       std::uninitialized_fill_n<std::vector<double, std::allocator<double>
>*, unsigned long, std::vector<double, std::allocator<double> > > (inlined)
          |                                               |                                               |
std::__uninitialized_fill_n<false>::__uninit_fill_n<std::vector<double, std::allocator<double>
>*, unsigned long, std::vector<double, std::allocator<double> > > (inlined)
          |       |       |       std::_Construct<std::vector<double, std::allocator<double> >,
std::vector<double, std::allocator<double> > const&> (inlined)
          |       |       |       std::vector<double, std::allocator<double> >::vector (inlined)
          |       |       |       |
          |       |       |       --3.40%--std::_Vector_base<double, std::allocator<double>
>::_Vector_base (inlined)
          |       |       |       |
          |       |       |       --3.22%--std::_Vector_base<double, std::allocator<double>
>::_M_create_storage (inlined)
          |       |       |               |
          |       |       |               --2.68%--std::_Vector_base<double,
std::allocator<double> >::_M_allocate (inlined)
          |       |       |                   std::allocator_traits<std::allocator<double>
>::allocate (inlined)
          |       |       |                   __gnu_cxx::new_allocator<double>::allocate
(inlined)
          |       |       |                    operator new
```

```
          |         |         |                              __GI___libc_malloc (inlined)
          |         |         |                              |
          |         |         |                               --2.49%--_int_malloc
          |         |         |
          |              |                 --1.44%--std::basic_ifstream<char,  std::char_traits<char>
>::basic_ifstream (inlined)
          |         |               std::basic_ifstream<char, std::char_traits<char> >::open (inlined)
          |         |               std::basic_filebuf<char, std::char_traits<char> >::open (inlined)
          |         |               std::basic_filebuf<char, std::char_traits<char> >::open
          |         |               |
          |         |                --1.08%--std::basic_filebuf<char, std::char_traits<char> >::open
          |           |                                  std::basic_filebuf<char,  std::char_traits<char>
>::_M_allocate_internal_buffer
          |           |                                  std::basic_filebuf<char,  std::char_traits<char>
>::_M_allocate_internal_buffer
          |         |                       operator new
          |         |                       __GI___libc_malloc (inlined)
          |         |                       _int_malloc
          |         |                       |
          |         |                        --0.54%--malloc_consolidate




--26.86%--loadPGM
                    |         |
                    |         |--20.08%--std::istream::operator>> (inlined)
                    |         |         |
                    |         |          --19.54%--std::istream::_M_extract<double>
                    |         |                    |
                    |       |              |--18.29%--std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::get (inlined)
                    |         |                    |         |
                    |              |                              |                --17.76%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::do_get
                    |         |                    |                    |
                    |           |                          |                          |--5.89%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::_M_extract_float
                    |         |                    |                    |         |
                    |          |                     |                    |         |--1.09%--std::operator!=<char,
std::char_traits<char> > (inlined)
                    |         |                    |                    |         |         std::istreambuf_iterator<char,
std::char_traits<char> >::equal
                    |         |                    |                    |         |         std::istreambuf_iterator<char,
std::char_traits<char> >::_M_at_eof (inlined)
```

```
                  |       |               |               |       |       std::istreambuf_iterator<char,
std::char_traits<char> >::_M_get (inlined)
                  |       |               |               |       |       |
                  |       |           |           |       |       --0.72%--std::basic_streambuf<char,
std::char_traits<char> >::sgetc (inlined)
                  |       |               |               |       |
                  |       |               |               |       |--1.07%--std::string::operator+=
(inlined)
                  |       |               |               |       |       |
                  |       |               |               |       |       --0.71%--std::string::push_back
                  |       |               |               |       |
                  |       |               |               |       |--0.54%--std::istreambuf_iterator<char,
std::char_traits<char> >::operator* (inlined)
                  |       |               |               |       |
                  |           |                           |                       |           |--0.54%--
std::__use_cache<std::__numpunct_cache<char> >::operator()
                  |       |               |               |       |
                  |       |               |               |       --0.54%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::_M_find<char> (inlined)
                  |       |               |               |
                  |       |               |               |--5.39%--std::__convert_to_v<double>
                  |       |               |               |       |
                  |       |           |           |       --4.86%--____strtod_l_internal (inlined)
                  |       |               |               |       |
                  |       |               |               |       |--0.73%--__GI_strlen (inlined)
                  |       |               |               |       |
                  |       |               |               |       --0.54%--round_and_return
                  |       |               |               |
                  |       |               |               |--2.90%--std::string::reserve
                  |       |               |               |       |
                  |       |               |               |       --2.36%--std::string::_Rep::_M_clone
                  |       |               |               |               |
                  |       |           |           |       --2.00%--std::string::_Rep::_S_create
                  |       |               |               |                       |
                  |           |                   |               |                       --1.82%--
__gnu_cxx::new_allocator<char>::allocate (inlined)
                  |       |               |               |                               |
                  |       |               |               |                               --1.64%--operator
new
                  |       |           |           |                                       __GI___libc_malloc
(inlined)
                  |       |               |               |                                       |
                  |       |               |               |                                       --0.73%--
_int_malloc
                  |       |               |               |
```

```
                    |          |                    |                    |--1.44%--std::basic_string<char,
std::char_traits<char>, std::allocator<char> >::~basic_string (inlined)
                    |          |                    |                    std::string::_Rep::_M_dispose (inlined)
                    |          |                    |                    |
                    |          |                    |                    --0.72%--_int_free
                    |          |                    |                    |
                    |          |                    |                    --0.55%--std::operator==<char,
std::char_traits<char> > (inlined)
                    |          |                    |
                    |          |                    --0.89%--std::istream::sentry::sentry
                    |          |
                    |          |--4.12%--Matrix::Matrix
                    |          |          std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::vector (inlined)
                    |          |          std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::_M_fill_initialize (inlined)
                    |          |          std::__uninitialized_fill_n_a<std::vector<double,
std::allocator<double> >*, unsigned long, std::vector<double, std::allocator<double> >,
std::vector<double, std::allocator<double> > > (inlined)
                    |          |          std::uninitialized_fill_n<std::vector<double, std::allocator<double>
>*, unsigned long, std::vector<double, std::allocator<double> > > (inlined)
                    |          |                                                                    |
std::__uninitialized_fill_n<false>::__uninit_fill_n<std::vector<double, std::allocator<double>
>*, unsigned long, std::vector<double, std::allocator<double> > > (inlined)
                    |          |          std::_Construct<std::vector<double, std::allocator<double> >,
std::vector<double, std::allocator<double> > const&> (inlined)
                    |          |          std::vector<double, std::allocator<double> >::vector (inlined)
                    |          |          |
                    |          |          |--3.40%--std::_Vector_base<double, std::allocator<double>
>::_Vector_base (inlined)
                    |          |          |          std::_Vector_base<double, std::allocator<double>
>::_M_create_storage (inlined)
                    |          |          |          std::_Vector_base<double, std::allocator<double>
>::_M_allocate (inlined)
                    |          |          |          std::allocator_traits<std::allocator<double> >::allocate
(inlined)
                    |          |          |          __gnu_cxx::new_allocator<double>::allocate (inlined)
                    |          |          |          |
                    |          |          |          --3.22%--operator new
                    |          |          |                    |
                    |          |          |                    --3.05%--__GI___libc_malloc (inlined)
                    |          |          |                              |
                    |          |          |                              --1.97%--_int_malloc
                    |          |          |
```

```
                |                                   |                                                --0.72%--
std::__uninitialized_copy_a<__gnu_cxx::__normal_iterator<double                                  const*,
std::vector<double, std::allocator<double> > >, double*, double> (inlined)
                |      |              std::uninitialized_copy<__gnu_cxx::__normal_iterator<double
const*, std::vector<double, std::allocator<double> > >, double*> (inlined)
                |                                                                                 |
std::__uninitialized_copy<true>::__uninit_copy<__gnu_cxx::__normal_iterator<double
const*, std::vector<double, std::allocator<double> > >, double*> (inlined)
                |      |                 std::copy<__gnu_cxx::__normal_iterator<double const*,
std::vector<double, std::allocator<double> > >, double*> (inlined)
                |                  |                                        std::__copy_move_a2<false,
__gnu_cxx::__normal_iterator<double const*, std::vector<double, std::allocator<double> > >,
double*> (inlined)
                |         |                   std::__copy_move_a<false, double const*, double*>
(inlined)
                |                  |                                      std::__copy_move<false,  true,
std::random_access_iterator_tag>::__copy_m<double> (inlined)
                |       |                |
                |       |                 --0.54%--__memcpy_ssse3_back
                |       |
                |                        --1.07%--std::basic_ifstream<char,  std::char_traits<char>
>::basic_ifstream (inlined)
                |                |
                |                --0.89%--std::basic_ifstream<char, std::char_traits<char> >::open
(inlined)
                |                     std::basic_filebuf<char, std::char_traits<char> >::open
(inlined)
                |                     std::basic_filebuf<char, std::char_traits<char> >::open
                |                     std::basic_filebuf<char, std::char_traits<char> >::open
                |                               std::basic_filebuf<char, std::char_traits<char>
>::_M_allocate_internal_buffer
                |                               std::basic_filebuf<char, std::char_traits<char>
>::_M_allocate_internal_buffer
                |                     operator new
                |                     __GI___libc_malloc (inlined)
                |                     _int_malloc
                |                     malloc_consolidate
```

Description of performance improvement

Briefly describe the performance improvement you are implementing. Your description should document:

- Why you chose the specific aspect/feature to improve (obviously it should be supported by your `perf` data)

- What is the best-case improvement that you anticipate – for example, if you optimize a feature that takes 25% of runtime, then the best case would be a 25% reduction in runtime.
- Briefly describe what/how you plan to change the implementation

The loadPGM method takes up about 46% of the runtime by loading in the image everytime, regardless of if it has seen the image before. By improving this method, a best case scenario would be a 46% reduction in run time. I plan to cache the images as they are passed in, so that if the same image is sent for processing again, I can just return the already processed image.

Source code changes for performance improvement

Copy-paste parts of the program that you actually modified to improve performance:

Changes to Matrix.h/.cpp (if any)

Copy-paste only changes and not the whole source code.

Changes to NeuralNet.h/.cpp (if any)

Copy-paste only changes and not the whole source code.

Changes to main.cpp (if any)

Highlighted changes

```
static std::unordered_map<std::string, Matrix> matrices;
Matrix loadPGM(const std::string& path) {
    if (matrices.find(path) != matrices.end()) {
        return matrices[path];
    }
    std::ifstream file(path);
    if (!file.good()) {
        throw std::runtime_error("Unable to read " + path);
    }
    // First read the header and dimensions
    std::string hdr;
    int width, height;
    Val maxVal, value;
    file >> hdr >> width >> height >> maxVal;
    if (hdr != "P2") {
        throw std::runtime_error("Only P2 PGM format is supported");
    }
    // Create a column matrix to read all of the data and normalize it
```

```
    Matrix img(width * height, 1);
    for (int i = 0; (i < width * height); i++) {
        file >> value;
        img[i][0] = value / maxVal;
    }
    matrices[path] = img;
    return img;
}
```

Runtime statistics from performance improvement

Use the supplied SLURM script to collect runtime statistics for your enhanced implementation.

Rep	User time (sec)	Elapsed time (sec)	Peak memory (KB)
1	16.8	17.32	649108
2	16.51	17.07	649108
3	16.59	17.12	649104
4	16.64	17.18	649108
5	16.65	17.18	649108

Perf report data for the revised implementation

In the space below, copy-paste the `perf` profile data that highlights the effectiveness of your reimplementation to improve performance:

```
--5.00%--loadPGM
          |      |      |      |
          |      |      |      |--3.71%--Matrix::Matrix (inlined)
          |      |      |      |          std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::vector (inlined)
          |      |      |      |      |
          |                  |                  |                  |                  |--2.28%--
std::__uninitialized_copy_a<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*, std::vector<double, std::allocator<double> > > (inlined)
          |                  |                  |                  |                  |
std::uninitialized_copy<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*> (inlined)
          |                  |                  |                  |                  |
std::__uninitialized_copy<false>::__uninit_copy<__gnu_cxx::__normal_iterator<std::vector<
```

```
double, std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double>
>, std::allocator<std::vector<double, std::allocator<double> > > > >, std::vector<double,
std::allocator<double> >*> (inlined)
          |      |      |      |      |      std::_Construct<std::vector<double, std::allocator<double>
>, std::vector<double, std::allocator<double> > const&> (inlined)
          |      |      |      |      |      std::vector<double, std::allocator<double> >::vector
(inlined)
          |      |      |      |      |      std::_Vector_base<double, std::allocator<double>
>::_Vector_base (inlined)
          |      |      |      |      |      |
          |      |      |      |      |      |--1.72%--std::_Vector_base<double,
std::allocator<double> >::_M_create_storage (inlined)
          |      |      |      |      |      |      std::_Vector_base<double, std::allocator<double>
>::_M_allocate (inlined)
          |      |      |      |      |      |      std::allocator_traits<std::allocator<double>
>::allocate (inlined)
          |      |      |      |      |      |      __gnu_cxx::new_allocator<double>::allocate
(inlined)
          |      |      |      |      |      |      |
          |      |      |      |      |      |      --1.44%--operator new
          |      |      |      |      |      |            __GI___libc_malloc (inlined)
          |      |      |      |      |      |            |
          |      |      |      |      |      |            --1.15%--_int_malloc
          |      |      |      |      |      |
          |      |      |      |      |      --0.56%--std::_Vector_base<double,
std::allocator<double> >::_Vector_impl::_Vector_impl (inlined)
          |      |      |      |      |
          |      |      |      |      --1.43%--std::_Vector_base<std::vector<double,
std::allocator<double> >, std::allocator<std::vector<double, std::allocator<double> > >
>::_Vector_base (inlined)
          |      |      |      |      std::_Vector_base<std::vector<double,
std::allocator<double> >, std::allocator<std::vector<double, std::allocator<double> > >
>::_M_create_storage (inlined)
          |      |      |      |      std::_Vector_base<std::vector<double,
std::allocator<double> >, std::allocator<std::vector<double, std::allocator<double> > >
>::_M_allocate (inlined)
          |      |      |      |      std::allocator_traits<std::allocator<std::vector<double,
std::allocator<double> > > >::allocate (inlined)
          |      |      |      |      __gnu_cxx::new_allocator<std::vector<double,
std::allocator<double> > >::allocate (inlined)
          |      |      |      |      operator new
          |      |      |      |      __GI___libc_malloc (inlined)
          |      |      |      |      _int_malloc
          |      |      |      |      malloc_consolidate
          |      |      |      |
```

```
          |         |         |          --0.76%--std::istream::operator>> (inlined)
          |         |         |                    std::istream::_M_extract<double>
          |         |         |                    |
          |         |         |                    --0.51%--std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::get (inlined)
          |         |         |                              std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::do_get
          |         |         |                              std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::_M_extract_float
          |         |         |
          |                   --15.77%--loadPGM
          |                             |
          |                             |--11.44%--Matrix::Matrix
          |                             |          std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::vector (inlined)
          |                             |          |
          |                                                                    |                    |--9.78%--
std::__uninitialized_copy_a<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*, std::vector<double, std::allocator<double> > > (inlined)
          |                                                                    |                    |
std::uninitialized_copy<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*> (inlined)
          |                                                                    |                    |
std::__uninitialized_copy<false>::__uninit_copy<__gnu_cxx::__normal_iterator<std::vector<
double, std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double>
>, std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*> (inlined)
          |                             |         |          |
          |                               |         |          --9.50%--std::_Construct<std::vector<double,
std::allocator<double> >, std::vector<double, std::allocator<double> > const&> (inlined)
          |                             |         |                    std::vector<double, std::allocator<double>
>::vector (inlined)
          |                             |         |                    |
          |                               |         |                    |--6.76%--std::_Vector_base<double,
std::allocator<double> >::_Vector_base (inlined)
```

```
          |                          |          |                  |          std::_Vector_base<double,
std::allocator<double> >::_M_create_storage (inlined)
          |                      |       |              |       |
          |                      |       |              |        --6.19%--std::_Vector_base<double,
std::allocator<double> >::_M_allocate (inlined)
          |                  |      |           |            std::allocator_traits<std::allocator<double>
>::allocate (inlined)
          |                                          |              |                          |
__gnu_cxx::new_allocator<double>::allocate (inlined)
          |                      |       |              |              |
          |                      |       |              |               --5.92%--operator new
          |                      |       |              |                      |
          |                  |       |           |                      --5.63%--__GI___libc_malloc
(inlined)
          |                      |       |              |                          |
          |                        |       |              |                          --3.70%--
_int_malloc
          |                      |       |              |
          |                                       |          |                      --2.47%--
std::__uninitialized_copy_a<__gnu_cxx::__normal_iterator<double                const*,
std::vector<double, std::allocator<double> > >, double*, double> (inlined)
          |                                                                        |                 |
std::uninitialized_copy<__gnu_cxx::__normal_iterator<double    const*,    std::vector<double,
std::allocator<double> > >, double*> (inlined)
          |                                                                        |                 |
std::__uninitialized_copy<true>::__uninit_copy<__gnu_cxx::__normal_iterator<double
const*, std::vector<double, std::allocator<double> > >, double*> (inlined)
          |                  |      |                  std::copy<__gnu_cxx::__normal_iterator<double
const*, std::vector<double, std::allocator<double> > >, double*> (inlined)
          |                          |          |                          std::__copy_move_a2<false,
__gnu_cxx::__normal_iterator<double const*, std::vector<double, std::allocator<double> > >,
double*> (inlined)
          |                      |          |                      std::__copy_move_a<false, double
const*, double*> (inlined)
          |                          |          |                      std::__copy_move<false, true,
std::random_access_iterator_tag>::__copy_m<double> (inlined)
          |                      |       |                      |
          |                      |       |                       --1.89%--__memmove_ssse3_back
          |                      |       |
          |                              |          --1.40%--std::_Vector_base<std::vector<double,
std::allocator<double>  >,  std::allocator<std::vector<double,  std::allocator<double>  >  >
>::_Vector_base (inlined)
          |                              |                  std::_Vector_base<std::vector<double,
std::allocator<double>  >,  std::allocator<std::vector<double,  std::allocator<double>  >  >
>::_M_create_storage (inlined)
```

```
          |                                   |                                   std::_Vector_base<std::vector<double,
std::allocator<double> >, std::allocator<std::vector<double, std::allocator<double> > >
>::_M_allocate (inlined)
          |                         |                 std::allocator_traits<std::allocator<std::vector<double,
std::allocator<double> > > >::allocate (inlined)
          |                                   |                 __gnu_cxx::new_allocator<std::vector<double,
std::allocator<double> > >::allocate (inlined)
          |                                   |                 operator new
          |                                   |                 __GI___libc_malloc (inlined)
          |                                   |                 _int_malloc
          |                                   |                 |
          |                                   |                  --0.84%--malloc_consolidate
          |                                   |
          |                                   |--2.55%--std::istream::operator>> (inlined)
          |                                   |         |
          |                                   |          --2.29%--std::istream::_M_extract<double>
          |                                   |                   |
          |                         |         |--1.79%--std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::get (inlined)
          |                                   |         |         std::num_get<char, std::istreambuf_iterator<char,
std::char_traits<char> > >::do_get
          |                                   |                   |         |
          |                                             |                   |           --0.77%--std::num_get<char,
std::istreambuf_iterator<char, std::char_traits<char> > >::_M_extract_float
          |                                   |                   |
          |                                   |                    --0.50%--std::istream::sentry::sentry
          |                                   |
          |                                    --0.51%--Matrix::operator= (inlined)
          |                                             std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >::operator=
          |                                             std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double,          std::allocator<double>          >          >
>::_M_allocate_and_copy<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > > > > (inlined)
          |
std::__uninitialized_copy_a<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*, std::vector<double, std::allocator<double> > > (inlined)
          |
std::uninitialized_copy<__gnu_cxx::__normal_iterator<std::vector<double,
std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double> >,
std::allocator<std::vector<double, std::allocator<double> > > >, std::vector<double,
std::allocator<double> >*> (inlined)
```

```
          |
std::__uninitialized_copy<false>::__uninit_copy<__gnu_cxx::__normal_iterator<std::vector<
double, std::allocator<double> > const*, std::vector<std::vector<double, std::allocator<double>
>, std::allocator<std::vector<double, std::allocator<double> > > > >, std::vector<double,
std::allocator<double> >*> (inlined)
          |                                  std::_Construct<std::vector<double, std::allocator<double>
>, std::vector<double, std::allocator<double> > const&> (inlined)
          |                                 std::vector<double, std::allocator<double> >::vector (inlined)
          |                                          std::_Vector_base<double, std::allocator<double>
>::_Vector_base (inlined)
          |                                          std::_Vector_base<double, std::allocator<double>
>::_M_create_storage (inlined)
          |                                          std::_Vector_base<double, std::allocator<double>
>::_M_allocate (inlined)
          |                                    std::allocator_traits<std::allocator<double> >::allocate
(inlined)
          |                                  __gnu_cxx::new_allocator<double>::allocate (inlined)
          |                                  operator new
          |                                  __GI___libc_malloc (inlined)
          |
```

Comparative runtime analysis

Compare the runtimes (*i.e.*, before and after your changes) by fill-in the Runtime Comparison Template and copy-paste the full sheet in the space below:

Change tile for cases and the type of data you are entering		
Replicate#	**orig user time**	**new user time**
1	27.2	16.8
2	27.28	16.51
3	27.04	16.59
4	25.69	16.64
5	25.63	16.65
Average:	26.568	16.638
SD:	0.833648607	0.1061602562
95% CI Range:	1.035111462	0.1318153682
Stats:	**26.568 ± 1.04**	**16.638 ± 0.13**
T-Test (H_0: μ1=μ2)	0.000009183856966	

Inferences & Discussions

Now, using the data from the runtime statistics discuss (at least 5-to-6 sentences) the change in runtime characteristics (both time and memory) due to your changes. Compare and contrast key aspects/changes to the implementation. Include any additional inferences as to why one version performs better than the other.

The user time and elapsed dropped time each dropped significantly, from about 26 to about 16 and from about 27 to about 17 seconds which are massive improvements. The first call to loadPGM dropped from about 20% to 5% usage, and the second call dropped from 46% to 15%, combining for a 45% drop in run time which is pretty massive and awesome, especially for just four lines of code. The other side of this is that the memory was not as fortunate. The memory beforehand was about 3400 KB, after the changes, it was about 650,000 KB. So, for as great a decrease in runtime we had, we had an equally bad increase in memory used. It makes sense for both time and memory. The time decreases because we only load each image once because we store it once its loaded in, but because we store it instead of loading it each time, we increase our memory usage exponentially.