Assignment 1

Part 1

BLAS (Basic Linear Algebra Subprogram) and LAPACK (Linear Algebra PACK) are two of the most commonly used libraries in advanced research computing. They are used for vector and matrix operations that are commonly found in a plethora of algorithms. More importantly, they are more than libraries, as they define a standard programming interface. A programming interface is a set of function definitions that can be called to accomplish specific computation, for example the dot product of two vectors of double precision numbers, or the matrix product of two hermitian matrices of complex numbers.[1]

BLAS functionality is categorized into three sets of routines called "levels", which correspond to both the chronological order of definition and publication, as well as the degree of the polynomial in the complexities of algorithms.[2] The levels can be defined as follows:

1. Level 1: This level calculates vector operations such as vector addition, scalar multiplication with vectors, etc.[3] This level works on O(n) data and computes in O(n) time.
2. Level 2: This level works on matrix-vector operations, such as matrix vector multiplication, triangular matrix vector multiplication, etc.[4] This level computes on O(n^2) data in O(n^2) time.
3. Level 3: This level works on matrix-matrix operations, such as matrix-matrix multiplication, solving triangular matrix with multiple right-hand sides, etc.[5] This level works on O(n^3) data in O(n^3) time.[6]

Some common matrix vector operations are defined below:

1. **Axpy:** This routine performs a scalar multiplication of vector x by α, then adds it to vector y, updating y in place.[2]
$$\boldsymbol{y} \leftarrow \alpha \boldsymbol{x} + \boldsymbol{y}$$
2. **Gemv:** This routine computes a matric-vector product using a general matrix. The formula to compute matrix vector multiplication is as follows:
$$y \leftarrow alpha * op(A) * x + beta * y$$
   where:
   - op(A) is one of op(A) = A (Matrix of m x n dimensions), or op(A) = A^T (Triangular Matrix), or op(A) = A^H (Hermitian Matrix)
   - alpha and beta are scalars
   - A is m x n matrix
   - x and y are vectors[7]
3. **Gemm:** This routine computes a scalar-matrix-matrix product and add the result to a scalar-matrix product, with general matrices. The operation is defined as:

$$C \leftarrow alpha * op(A) * op(B) + beta * C$$

where:

- op(X) is one of op(X) = X (Matrix of m x n dimensions), or op(X) = X^T (triangular matrix), or op(X) = X^H (Hermitian matrix)
- alpha and beta are scalars
- A, B and C are matrices
- op(A) is m x k matrix
- op(B) is k x n matrix
- C is m x n matrix[8]

To implement BLAS and LAPACK, we may use Intel MKL, which is a library of optimized math routines for science, engineering, and financial applications. Core math functions include BLAS, LAPACK, ScaLAPACK, sparse solvers, fast Fourier transforms, and vector math. While BLAS and LAPACK are standard programming interfaces, Intel MKL is an implementation of the same, which is optimized for Intel and Linux systems, and offers many other optimized libraries for high performance computing.[9]

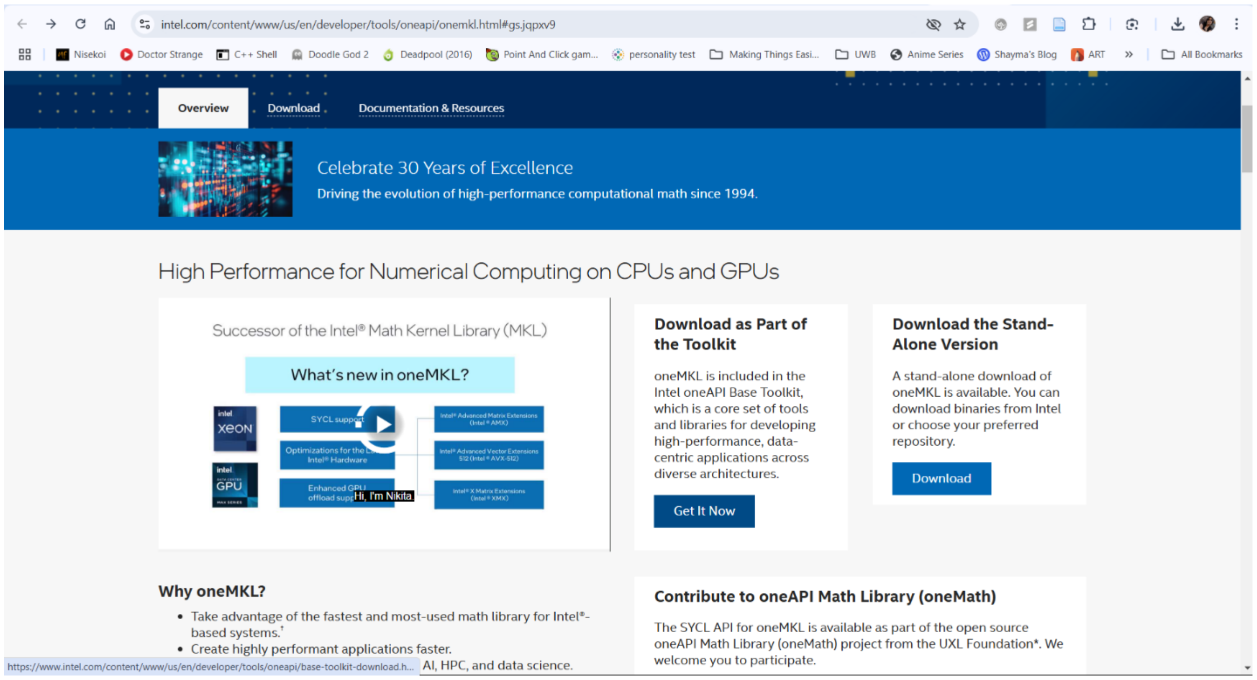
References:

[1] "BLAS and LAPACK - Alliance Doc." Accessed: Jan. 13, 2025. [Online]. Available: https://docs.alliancecan.ca/wiki/BLAS_and_LAPACK
[2] "Basic Linear Algebra Subprograms," *Wikipedia*. Dec. 26, 2024. Accessed: Jan. 14, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Basic_Linear_Algebra_Subprograms&oldid=1265318616
[3] "BLAS (Basic Linear Algebra Subprograms)." Accessed: Jan. 14, 2025. [Online]. Available: https://www.netlib.org/blas/#_level_1
[4] "BLAS (Basic Linear Algebra Subprograms)." Accessed: Jan. 14, 2025. [Online]. Available: https://www.netlib.org/blas/#_level_2
[5] "BLAS (Basic Linear Algebra Subprograms)." Accessed: Jan. 14, 2025. [Online]. Available: https://www.netlib.org/blas/#_level_3
[6] "Fortran 77 Tutorial." Accessed: Jan. 14, 2025. [Online]. Available: https://web.stanford.edu/class/me200c/tutorial_77/18.1_blas.html
[7] "gemv," Intel. Accessed: Jan. 14, 2025. [Online]. Available: https://www.intel.com/content/www/us/en/docs/onemkl/developer-reference-dpcpp/2024-1/gemv.html
[8] "gemm," Intel. Accessed: Jan. 14, 2025. [Online]. Available: https://www.intel.com/content/www/us/en/docs/onemkl/developer-reference-dpcpp/2023-2/gemm.html
[9] "Math Kernel Library," *Wikipedia*. Dec. 26, 2024. Accessed: Jan. 14, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Math_Kernel_Library&oldid=1265317883

Part 2

Installation of Intel oneAPI Math Kernel Library

1. To install MKL libraries in a Windows Operating System, you can refer this link: Intel oneAPI Library. You can click on "Get it now" under the "Download as Part of the Toolkit" container.



intel.com/content/www/us/en/developer/tools/oneapi/onemkl.html#gs.jqpxv9

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Successor of the Intel® Math Kernel Library (MKL)

What's new in oneMKL?

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oneMKL is included in the Intel oneAPI Base Toolkit, which is a core set of tools and libraries for developing high-performance, data-centric applications across diverse architectures.

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Download the Stand-Alone Version

A stand-alone download of oneMKL is available. You can download binaries from Intel or choose your preferred repository.

Download

Why oneMKL?

- Take advantage of the fastest and most-used math library for Intel®-based systems.†
- Create highly performant applications faster.

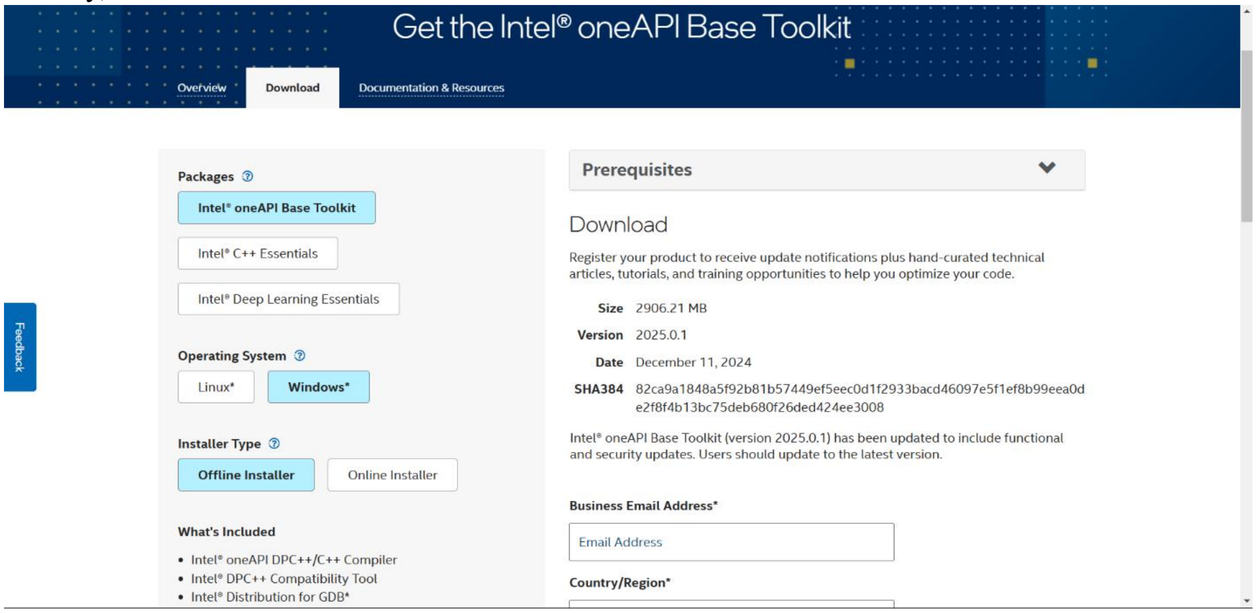
https://www.intel.com/content/www/us/en/developer/tools/oneapi/base-toolkit-download.h... AI, HPC, and data science.

Contribute to oneAPI Math Library (oneMath)

The SYCL API for oneMKL is available as part of the open source oneAPI Math Library (oneMath) project from the UXL Foundation*. We welcome you to participate.

xeon
GPU
SYCL support
Optimizations for the Intel® Hardware
Enhanced GPU offload support
Hi, I'm Nikita
Intel® Advanced Matrix Extensions (Intel® AMX)
Intel® Advanced Vector Extensions 512 (Intel® AVX-512)
Intel® X Matrix Extensions (Intel® XMX)

2. Fill out the details of your specific system and your details such as your email address and country, then download the file.



Get the Intel® oneAPI Base Toolkit

Overview · Download · Documentation & Resources

Packages

Intel® oneAPI Base Toolkit (selected) · Intel® C++ Essentials · Intel® Deep Learning Essentials

Operating System

Linux* · Windows* (selected)

Installer Type

Offline Installer (selected) · Online Installer

What's Included

- Intel® oneAPI DPC++/C++ Compiler
- Intel® DPC++ Compatibility Tool
- Intel® Distribution for GDB*

Prerequisites

Download

Register your product to receive update notifications plus hand-curated technical articles, tutorials, and training opportunities to help you optimize your code.

Size	2906.21 MB
Version	2025.0.1
Date	December 11, 2024
SHA384	82ca9a1848a5f92b81b57449ef5eec0d1f2933bacd46097e5f1ef8b99eea0d e2f8f4b13bc75deb680f26ded424ee3008

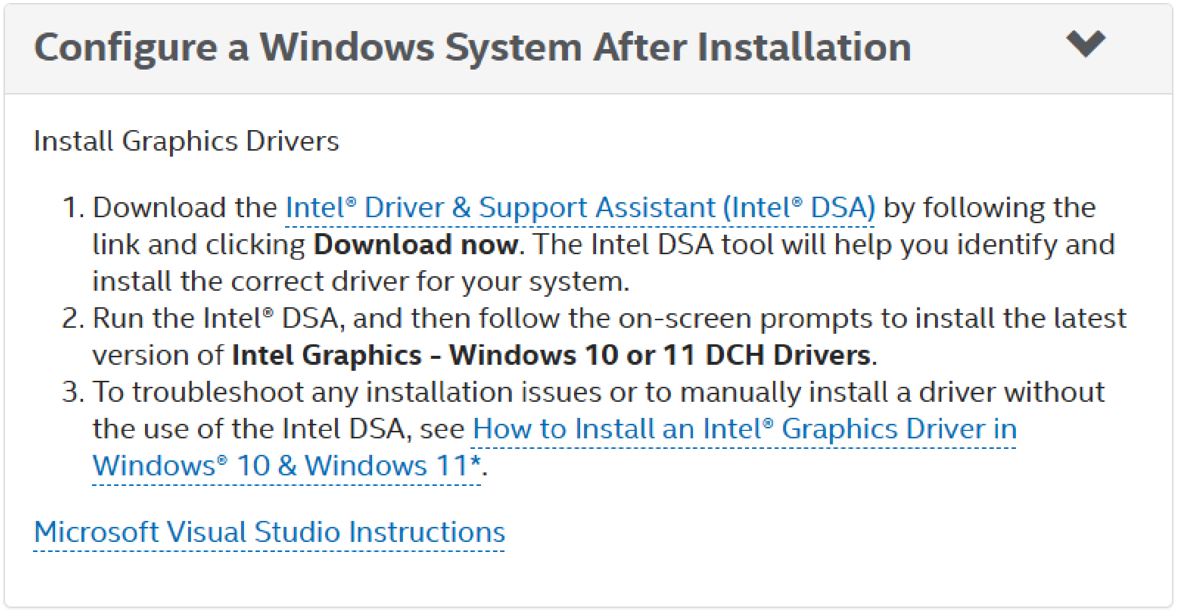
Intel® oneAPI Base Toolkit (version 2025.0.1) has been updated to include functional and security updates. Users should update to the latest version.

Business Email Address*

Email Address

Country/Region*

3. Additionally, you can also download the Intel Driver and Support Assistant to upgrade the drivers on your system to better work with Intel oneAPI MKL. After downloading and opening the Assistant, follow onscreen instructions to update drivers.



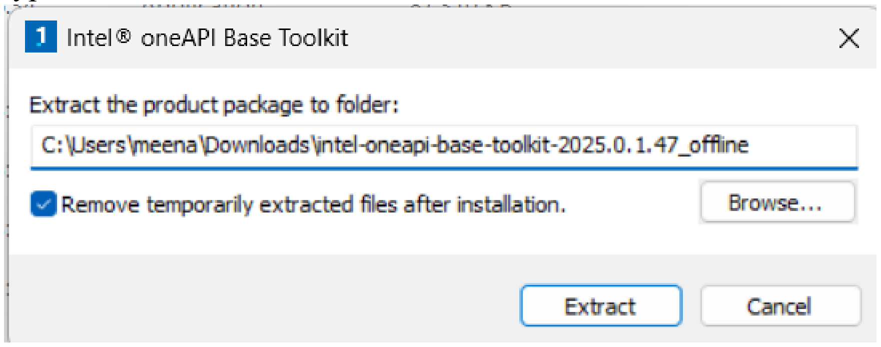
Configure a Windows System After Installation

Install Graphics Drivers

1. Download the Intel® Driver & Support Assistant (Intel® DSA) by following the link and clicking **Download now**. The Intel DSA tool will help you identify and install the correct driver for your system.
2. Run the Intel® DSA, and then follow the on-screen prompts to install the latest version of **Intel Graphics - Windows 10 or 11 DCH Drivers**.
3. To troubleshoot any installation issues or to manually install a driver without the use of the Intel DSA, see How to Install an Intel® Graphics Driver in Windows® 10 & Windows 11*.

Microsoft Visual Studio Instructions

4. After downloading, open the exe file, and follow the instructions in the installer. Choose the typical installation.



Intel® oneAPI Base Toolkit

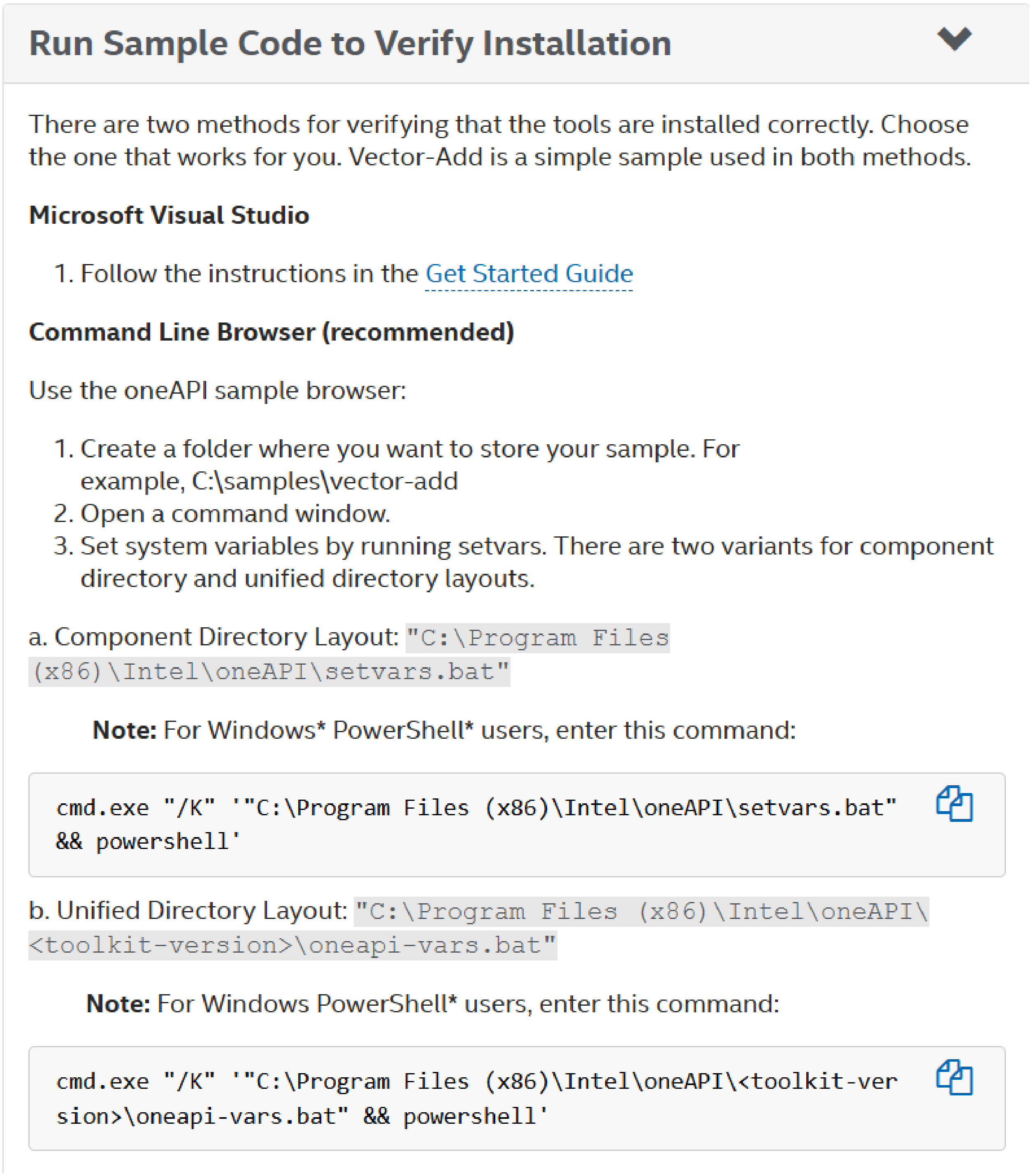
Extract the product package to folder:

C:\Users\meena\Downloads\intel-oneapi-base-toolkit-2025.0.1.47_offline

☑ Remove temporarily extracted files after installation.

Testing the installation of Intel oneAPI Math Kernel Library

1. On the same page where you downloaded the library, you can find a section on how you can test the library configuration, or you can follow the below steps.



Run Sample Code to Verify Installation

There are two methods for verifying that the tools are installed correctly. Choose the one that works for you. Vector-Add is a simple sample used in both methods.

Microsoft Visual Studio

1. Follow the instructions in the Get Started Guide

Command Line Browser (recommended)

Use the oneAPI sample browser:

1. Create a folder where you want to store your sample. For example, C:\samples\vector-add
2. Open a command window.
3. Set system variables by running setvars. There are two variants for component directory and unified directory layouts.

a. Component Directory Layout: `"C:\Program Files (x86)\Intel\oneAPI\setvars.bat"`

Note: For Windows* PowerShell* users, enter this command:

```
cmd.exe "/K" '"C:\Program Files (x86)\Intel\oneAPI\setvars.bat"
&& powershell'
```

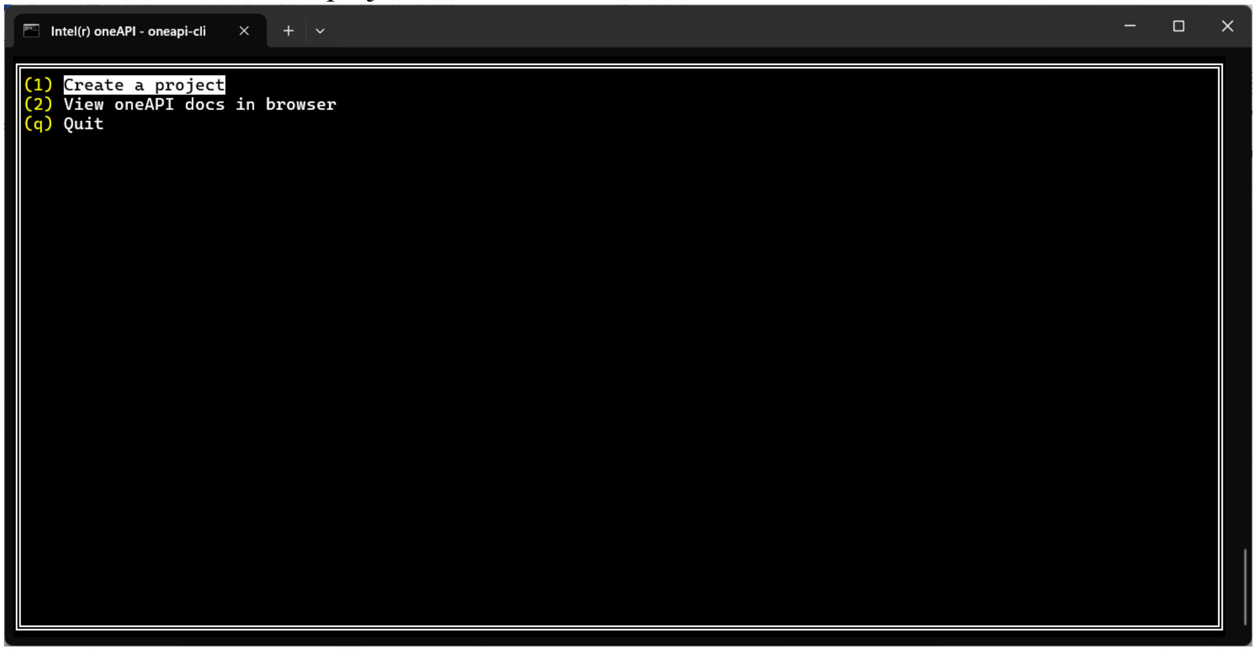
b. Unified Directory Layout: `"C:\Program Files (x86)\Intel\oneAPI\<toolkit-version>\oneapi-vars.bat"`

Note: For Windows PowerShell* users, enter this command:

```
cmd.exe "/K" '"C:\Program Files (x86)\Intel\oneAPI\<toolkit-ver
sion>\oneapi-vars.bat" && powershell'
```

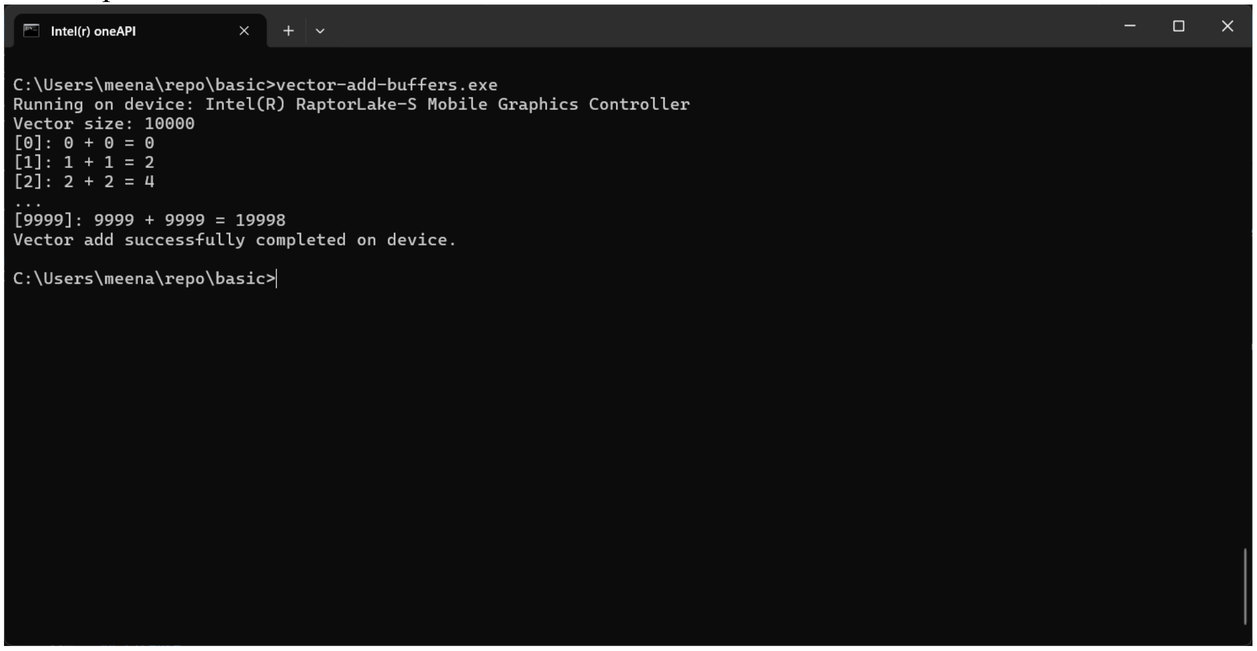
2. On your system find the application called Intel® oneAPI. Type in the command line “oneapi-cli”.

3. Click enter for “Create a project”.



```
(1) Create a project
(2) View oneAPI docs in browser
(q) Quit
```

4. Click enter for “cpp”.
5. Navigate to “Base: Vector Add” and press enter for it.
6. Specify the location where the files will be added.
7. Open the README.md in another file editor like Microsoft VS code.
8. You can go through these steps to execute the code. You may need to install MSYS2 and CMake to run C++ files.
9. The output should look like this:



```
C:\Users\meena\repo\basic>vector-add-buffers.exe
Running on device: Intel(R) RaptorLake-S Mobile Graphics Controller
Vector size: 10000
[0]: 0 + 0 = 0
[1]: 1 + 1 = 2
[2]: 2 + 2 = 4
...
[9999]: 9999 + 9999 = 19998
Vector add successfully completed on device.

C:\Users\meena\repo\basic>
```