NVIDIA NVSHMEM

Installation Guide

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Chapter 1. Overview

NVIDIA® NVSHMEM™ is a programming interface that implements a Partitioned Global Address Space (PGAS) model across a cluster of NVIDIA GPUs. NVSHMEM provides an easy-to-use interface to allocate memory that is symmetrically distributed across the GPUs. In addition to a CPU-side interface, NVSHMEM also provides a CUDA kernel-side interface that allows CUDA® threads to access any location in the symmetrically-distributed memory.

Chapter 2. Hardware And Software Requirements

NVIDIA® NVSHMEM™ has the following hardware and software requirements.

2.1. Hardware Requirements

NVSHMEM requires the following hardware:

- The `x86_64` or `ppc64le` CPU architectures.
- NVIDIA Data Center GPU of the NVIDIA Volta™ GPU architecture or later.

  For a complete list, refer to https://developer.nvidia.com/cuda-gpus.
- All GPUs must be P2P-connected via NVLink/PCIe or via GPUDirect RDMA over InfiniBand/RoCE with a Mellanox adapter (CX-4 or later).

  Support for atomics requires a NVLink connection or a GPUDirect RDMA connection and GDRCopy. See Software Requirements for more information.

2.2. Software Requirements

NVSHMEM requires the following software:

- 64-bit Linux.

  For a complete compatibility matrix, see the NVIDIA CUDA Installation Guide for Linux .
- A C++ Compiler with C++11 support.
- CUDA 10.2 or later.
- GNU Make 3.81 or later.
- (**Optional**) Mellanox OFED.

  This software is required to build the IBRC transport. If the OFED is unavailable, NVSHMEM can be built with `NVSHMEM_IBRC_SUPPORT=0` set in the environment.
- (**Optional**) `nv_peer_mem` for GPUDirect RDMA.

  This software must use the IBRC and UCX transports and is required when `NVSHMEM_IBRC_SUPPORT=0` and `NVSHMEM_UCX_SUPPORT=0` are **not set** at compile time.

- PMI-1 (for example, Hydra), PMI-2 (for example, slurm), or a PMIx compatible launcher.
- (**Optional**) GDRCopy v2.0 or later.
  - This software is required for atomics support on non-NVLink connections.
  - It is required when `NVSHMEM_IBRC_SUPPORT=0` and `NVSHMEM_UCX_SUPPORT=0` are **not set** at compile time.
- (**Optional**) UCX version 1.10.0 or later.

  This software is required to build the UCX transport.

  Note: UCX must be configured with `--enable-mt` and `--with-dm`.
- (**Optional**) NCCL 2.0 or later.
- (**Optional**) PMIx 3.1.5 or later.

2.3. System Requirements

Here is some information about an additional system requirement.

(**Optional**) **CUDA MPS Service**

When using multiple processes-per-GPU, to support the complete NVHSMEM API, the CUDA MPS server must be configured on the system. To avoid deadlock situations, the total GPU Utilization that is shared between the processes must be capped at 100% or lower.

Refer to Multi-Process Service for more information about how to configure the MPS server.

Chapter 3. Installation

3.1. Downloading NVSHMEM

Procedure

Download and extract the NVSHMEM txz archive from https://developer.download.nvidia.com/compute/redist/nvshmem/version-number/source (for example, https://developer.download.nvidia.com/compute/redist/nvshmem/2.4.1/source/).

The extracted directory contains the following files and subdirectories:

File or Directory	Description
`src/`	Contains NVSHMEM sources and headers.
`perftest/`	Contains tests showing use of NVSHMEM APIs with performance reporting.
`examples/`	Contains examples showing use of some common use cases of NVSHMEM.
`scripts/`	Contains helper scripts, for example, the script to download, build, and install Hydra.
`changelog`	Change history for the repository.
`COPYRIGHT.txt`	Copyright information.
`NVSHMEM-SLA.txt`	NVSHMEM Software License Agreement (SLA).

3.2. Building And Installing NVSHMEM

Procedure

1. Set the `CUDA_HOME` environment variable to point to the CUDA Toolkit.
2. Set the `GDRCOPY_HOME` environment variable to point to the GDRCopy installation.

   To build without GDRCopy, set the environmental variable to `NVSHMEM_USE_GDRCOPY=0`.

Note: Without GDRCopy, atomics are only supported across NVLink connections.

3. If MPI and/or SHMEM support is required, set `NVSHMEM_MPI_SUPPORT=1` and/or `NVSHMEM_SHMEM_SUPPORT=1`.
4. Set the `MPI_HOME` and `SHMEM_HOME` environment variables to point to the MPI and OpenSHMEM installations, respectively.
5. By default, the location of `mpicc` that is used during NVSHMEM compilation is set to `$MPI_HOME/bin/mpicc`.

   This location can be overridden by specifying `MPICC=<path/to/mpicc>` in the environment.

> **Note:** Here is some additional information:
>
> - When using Open MPI and OSHMEM, the paths are the same.
> - To use OSHMEM, Open MPI needs to be built with UCX support.
> - NVSHMEM has been tested with Open MPI 4.0.1 and UCX 1.10.
> - Other MPI and OpenSHMEM installations should work.
> - By default, MPI support is enabled, and OpenSHMEM support is disabled.

6. **Optional:** To enable UCX support, set `NVSHMEM_UCX_SUPPORT=1` and `UCX_HOME` to the installed UCX directory.
7. **Optional:** To enable NCCL support, set `NVSHMEM_USE_NCCL=1` and `NCCL_HOME` to the installed NCCL directory.
8. **Optional:** To enable PMIx support, set `NVSHMEM_PMIX_SUPPORT=1` and `PMIX_HOME` to the installed PMIx directory.
9. **Optional:** Configure the default bootstrap:
   - The PMI bootstrap method can be selected by using the `NVSHMEM_BOOTSTRAP_PMI` environment variable.

     PMI-1, which can be used with the Hydra launcher, is the default PMI standard that is used by NVSHMEM.
   - To select PMIx as the default PMI interface, set `NVSHMEM_DEFAULT_PMIX=1`.
   - To select PMI-2 as the default PMI interface, set `NVSHMEM_DEFAULT_PMI2=1`.
10. Set `NVSHMEM_PREFIX` to specify the location where NVSHMEM will be installed.
11. To build and install the library, run `make -j install`.

3.3. Using NVSHMEM In Your Applications

3.3.1. Launching NVSHMEM Programs

NVSHMEM supports the following methods to launch your application:

- Use of a PMI-1 compatible launcher, such as Hydra.
- Use of a PMI-2 compatible launcher, such as Slurm.

- Use of a PMIx compatible launcher, such as Slurm or Open MPI mpirun.
- Launching as part of an existing MPI application.
- Launching as part of an existing OpenSHMEM application.

The PMI-1 and PMI-2 clients are in NVSHMEM and are automatically built as part of the build process. A PMIx client must be provided by the user by installing Open PMIx or by using the PMIx client that is installed by Open MPI or Slurm. When you build Open MPI, include the `--enable-install-libpmix configure` option. When you build NVSHMEM, set `NVSHMEM_PMIX_SUPPORT=1` and `PMIX_HOME=/path/to/openmpi`.

To select the correct PMI library at runtime, set `NVSHMEM_BOOTSTRAP_PMI` to `PMI`, `PMI-2`, or `PMIx`. To bootstrap NVSHMEM by using MPI or OpenSHMEM, launch the application in the typical way and call the `nvshmemx_init_attr` function to inform NVSHMEM that NVSHMEM is running as part of an existing MPI or OpenSHMEM job.

3.3.2. Using NVSHMEM With Your C Or C++ Program

Procedure

1. Include `nvshmem.h` and `nvshmemx.h` from `include/`.
2. Point to the `include/` and `lib/` paths.
3. **NVSHMEM users**: If your C or C++ program only uses NVSHMEM, install Hydra Process Manager using the `install_hydra.sh` bash script under the `scripts/` directory.
   a). Provide the download and install location as arguments, for example:

   ```
   ./install_hydra.sh <download_path> <install_path>
   ```

   b). To run the NVSHMEM job, use `nvshmrun` launcher, which is located under `bin/` in the Hydra install path.

3.3.3. Using NVSHMEM With Your MPI or OpenSHMEM Program

Here is some information about how to use NVSHMEM with your MPI or OpenSHMEM program.

Note: The only currently tested MPI library is Open MPI, but any standard compliant MPI library should work.

To run a Hybrid MPI + NVSHMEM program, use the `mpirun` launcher in the MPI installation.

Similarly, NVSHMEM can be used from OpenSHMEM programs, but you cannot use the launchers in the NVSHMEM package. The only currently tested OpenSHMEM version is OSHMEM in Open MPI. Other OpenSHMEM implementations, such as Sandia OpenSHMEM (SOS) should also work. To run the hybrid OpenSHMEM/NVSHMEM job, use the `oshrun` launcher in the OpenMPI installation or follow the launcher specification of your OpenSHMEM

library. The `nvshmemx_init_attr` initialization routine **must be** used to enable the OpenSHMEM bootstrap.

NVSHMEM relies on a plugin system for bootstrapping with MPI. By default, an MPI bootstrap plugin is built for NVSHMEM and is installed in `$(NVSHMEM_BUILDDIR)/lib`. If this directory is not in your dynamic linker search path, you might need to add it to `$LD_LIBRARY_PATH`. This MPI plugin is selected automatically at runtime if the `nvshmemx_init_attr` initialization function is used to request the MPI bootstrap, or if `NVSHMEM_BOOTSTRAP="MPI"` is set.

The source code of the MPI bootstrap plugin is installed in `$(NVSHMEM_BUILDDIR)/share/nvshmem/src/bootstrap-plugins` and can be built separately from the NVSHMEM library (for example, to support additional MPI libraries). Custom bootstrap plugins are also possible and should implement the interface that is defined in `$(NVSHMEM_BUILDDIR)/include/nvshmem_bootstrap.h`. Plugins must be built as relocatable shared objects. After the external plugin library is built, it can be specified to NVSHMEM at runtime by specifying `NVSHMEM_BOOTSTRAP="plugin"` and `NVSHMEM_BOOTSTRAP_PLUGIN="[name of plugin]"`. For example, `NVSHMEM_BOOTSTRAP="MPI"` is equal to `NVSHMEM_BOOTSTRAP="plugin"` and `NVSHMEM_BOOTSTRAP_PLUGIN="nvshem_bootstrap_mpi.so"`.

3.4. Running Performance Tests

Before you can run performance tests, you first must build them.

Procedure

1. If the NVSHMEM library was built with `NVSHMEM_MPI_SUPPORT=1`, set the `CUDA_HOME`, `NVSHMEM_HOME` and `MPI_HOME` environment variables to build NVSHMEM performance tests:

   ```
   CUDA_HOME=<path to supported CUDA installation>
   NVSHMEM_HOME=<path to directory where NVSHMEM is installed>
   MPI_HOME=<path to MPI installation>
   ```

   If you have built NVSHMEM with MPI and OpenSHMEM support (`NVSHMEM_MPI_SUPPORT=1` and `NVSHMEM_SHMEM_SUPPORT=1`) when you build `perftest/`, MPI and OpenSHMEM support must be enabled.

   Build without SHMEM interoperability: To build NVSHMEM performance tests without SHMEM interoperability, set the environment variable `NVSHMEM_SHMEM_SUPPORT` to `0`. By default, performance tests are installed under `perftest/perftest_install`. To install to a different path, set `NVSHMEM_PERFTEST_INSTALL` to point to the correct path.
2. Update `LD_LIBRARY_PATH` to point to `$CUDA_HOME/lib64` and `$MPI_HOME/lib`.
3. Assuming Hydra is installed under `HYDRA_HOME`, run performance tests as NVSHMEM jobs, hybrid MPI+NVSHMEM jobs, or hybrid OpenSHMEM+NVSHMEM jobs with the following commands (using `perftest/device/pt-to-pt/put.cu` as an example):

   NVSHMEM job using Hydra (PMI-1):

   ```
   $HYDRA_HOME/bin/nvshmrun -n <up to number of P2P or InfiniBand
   NIC accessible GPUs>
   $NVSHMEM_PERFTEST_INSTALL/device/pt-to-pt/shmem_put_bw
   ```

   NVSHMEM job using slurm:

   ```
   srun -n <up to number of P2P or InfiniBand NIC accessible GPUs>
   ```

```
$NVSHMEM_PERFTEST_INSTALL/device/pt-to-pt/shmem_put_bw
```

Note: When slurm was built with a PMI that does not match the default of NVSHMEM, for example, if slurm was built with PMIx support and `NVSHMEM_DEFAULT_PMIX=1` was not set when building NVSHMEM, `NVSHMEM_BOOTSTRAP_PMI` can be used to override the default. Possible values are PMIX, PMI-2, and PMI.

Hybrid MPI/NVSHMEM job:

```
$MPI_HOME/bin/mpirun -n <up to number of GPUs accessible by P2P
or InfiniBand NIC> -x NVSHMEMTEST_USE_MPI_LAUNCHER=1
$NVSHMEM_PERFTEST_INSTALL/device/pt-to-pt/shmem_put_bw
```

Hybrid OpenSHMEM/NVSHMEM job:

```
$MPI_HOME/bin/oshrun -n <up to number of GPUs accessible by P2P
or InfiniBand NIC> -x USE_SHMEM_IN_TEST=1
$NVSHMEM_PERFTEST_INSTALL/device/pt-to-pt/shmem_put_bw
```

3.5. "Hello World" Example

Procedure

1. Save the following code as `nvshmemHelloWorld.cu`:

```
#include <stdio.h>
#include <cuda.h>
#include <nvshmem.h>
#include <nvshmemx.h>

__global__ void simple_shift(int *destination) {
    int mype = nvshmem_my_pe();
    int npes = nvshmem_n_pes();
    int peer = (mype + 1) % npes;

    nvshmem_int_p(destination, mype, peer);
}

int main(void) {
    int mype_node, msg;
    cudaStream_t stream;

    nvshmem_init();
    mype_node = nvshmem_team_my_pe(NVSHMEMX_TEAM_NODE);
    cudaSetDevice(mype_node);
    cudaStreamCreate(&stream);

    int *destination = (int *) nvshmem_malloc(sizeof(int));

    simple_shift<<<1, 1, 0, stream>>>(destination);
    nvshmemx_barrier_all_on_stream(stream);
    cudaMemcpyAsync(&msg, destination, sizeof(int), cudaMemcpyDeviceToHost,
 stream);

    cudaStreamSynchronize(stream);
    printf("%d: received message %d\n", nvshmem_my_pe(), msg);

    nvshmem_free(destination);
    nvshmem_finalize();
    return 0;
}
```

2. Build `nvshmemHelloWorld.cu` with the following command:

```
nvcc -rdc=true -ccbin g++ -gencode=$NVCC_GENCODE -I $NVSHMEM_HOME/include
 nvshmemHelloWorld.cu -o nvshmemHelloWorld.out -L $NVSHMEM_HOME/lib -lnvshmem
-lcuda
```

Where `arch=compute_70,code=sm_70` is the value of `NVCC_GENCODE` for V100 GPUs.

3. Run the `nvshmemHelloWorld` sample with one of the following commands:

   - When running on one host with 2 GPUs (connected by PCI-E, NVLink or Infiniband):

     ```
     $HYDRA_HOME/bin/nvshmrun -n 2 -ppn 2 ./nvshmemHelloWorld.out
     ```

   - When running on two hosts with 1 GPU per host that is connected by InfiniBand:

     ```
     $HYDRA_HOME/bin/nvshmrun -n 2 -ppn 1 --hosts hostname1,hostname2 ./
     nvshmemHelloWorld.out
     ```

Chapter 4. Support

Report bugs and submit feature requests by using NVONLINE or by emailing nvshmem@nvidia.com.

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