

# Extending and Reproducing pSTL-Bench: oneDPL Backend Integration and Enhanced Reproducibility

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## Abstract

Describe in concise words what you do, why you do it (not necessarily in this order), and the main result. The abstract has to be self-contained and readable for a person in the general area. You should write the abstract last.

## 1 Introduction

Writing performance-portable and efficient parallel applications remains a significant challenge due to the diversity of modern hardware architectures. The emergence of parallel programming frameworks and, more recently, the introduction of parallel algorithms in the *C++17 Standard Template Library (STL)* aim to address this challenge by enabling developers to write code that runs efficiently across CPUs and GPUs using a standardized interface.

*pSTL-Bench* [1] is a benchmark suite originally developed to quantitatively evaluate the performance of individual parallel STL algorithms across various compiler frameworks (such as GCC, Intel's icpx, NVIDIA HPC SDK) and backends (including TBB, HPX, OpenMP, and CUDA). It provides a focused, micro-benchmarking approach that avoids the complexities of full applications and highlights the relative performance characteristics of different STL implementations.

**This Work.** In this work, the main results and experiments from the original pSTL-Bench paper are reproduced. Beyond reproduction, the project is then extended by incorporating support for the *oneAPI DPC++ Library (oneDPL)* backend, enabling the evaluation of Intel's parallel STL implementation based on the *SYCL programming model* on both CPU and GPU platforms.

To further enhance the usability and reproducibility of the benchmark suite, automation tools are introduced, including Ansible playbooks for environment setup and benchmark execution, R scripts for performance analysis, and expanded documentation for ease of deployment and adding new backends.

**Related Work.** This work builds directly on pSTL-Bench. While performance portability and parallelism have been widely studied in the context of full applications [2] and frameworks such as Kokkos [3] and RAJA [4], no prior work has reproduced or extended pSTL-Bench, nor added support for the oneDPL backend or focused on improving its reproducibility.

## 2 Background

This section introduces the relevant concepts and context for evaluating the scalability of parallel algorithms implemented in the C++ Standard Template Library (STL). It defines the scope of the problem, outlines the algorithms under analysis, and describes the supporting frameworks and benchmarking strategies used for performance assessment.

**Parallel STL in C++.** Since C++17, the Standard Template Library (STL) includes parallel versions of many common algorithms,

enabling hardware parallelism through familiar interfaces. Compiler support varies, relying on different runtimes and libraries to target platforms such as multi-core CPUs and GPUs, with differences in scheduling, memory use, and synchronization.

**Problem Definition.** The primary objective is to analyze how different implementations of parallel STL algorithms scale with increasing problem sizes and hardware resources. This includes identifying the computational overheads and the performance gains achieved through parallel execution. A detailed performance comparison is necessary to understand which combinations of compilers and backends provide the most efficient use of available computing resources.

**Algorithms.** The study focuses on five representative algorithms that embody diverse computational patterns:

- **find** – Searches for a target value within a range using linear traversal.
- **for\_each** – Executes a loop with  $k_{it}$  increments per element to simulate computation and stores the result.  $k_{it}$  is a parameter that can be adjusted to control the workload.
- **inclusive\_scan** – Produces a prefix sum, where each element in the output is the sum of all previous elements plus the current element, requiring synchronization.
- **reduce** – Computes a single result by summing all elements in a range, which can be parallelized but requires synchronization to combine results.
- **sort** – Rearranges elements into ascending order, requiring synchronization and data movement.

**Backends.** In this work, support for the *oneAPI DPC++ Library (oneDPL)* is added, which is based on the SYCL programming model and enables parallel STL execution on both CPUs and GPUs.

The original pSTL-Bench suite includes the following backends:

- **GNU Parallel STL** – The GCC implementation of parallel algorithms using OpenMP.
- **TBB** – A C++ library offering task-based parallel algorithms and data structures.
- **HPX** – A C++ runtime for fine-grained parallel and distributed applications.
- **OpenMP** – A standard API for shared-memory parallel programming.
- **CUDA** – NVIDIA's platform for general-purpose GPU computing.

The evaluation covers various compiler-backend combinations, including those based on GNU, Intel, and NVIDIA compilers.

**Automation.** To facilitate reproducibility and ease of use, the project includes automation tools:

- **Ansible** – An agentless automation tool that simplifies the setup of the benchmark environment, including installation

of dependencies, configuration of the system, compilation of the benchmark suite, and execution of tests.

- **Semaphore UI** – A web-based interface for managing and monitoring the execution of ansible playbooks, providing a user-friendly way to trigger tests and view results.
- **R Scripts** – Scripts for analyzing performance data, generating plots similar to those in the original paper, and providing insights into the performance characteristics of different implementations.

### 3 Benchmark Setup

This section describes the hardware and software setup used for the benchmarking experiments, including platform specifications, compiler versions, and the configuration of the parallel STL implementations.

**Hardware Platform.** The benchmarks were executed on a *DELL G16 7630* laptop connected to external power, with the hardware specifications shown in Table 1.

**Table 1: Hardware configuration**

CPU [5]	
Processor	Intel Core i9-13900HX
Cores	24 (8 P-cores + 16 E-cores)
Core Frequency	2.20 GHz (up to 5.40 GHz)
Threads	32 threads
Memory	32 GB RAM
GPU [6]	
GPU	NVIDIA GeForce RTX 4070 (mobile)
CUDA Cores	4608 CUDA cores
Core Frequency	1230 MHz (up to 2175 MHz)
Memory	8 GB GDDR6 VRAM

**Software Platform.** The benchmarks were executed on a Linux-based operating system, specifically *Ubuntu 25.04 Desktop*. The desktop version was used due to GPU driver compatibility issues with the server edition. Prior to execution, the CPU frequency governor was set to *performance* mode to ensure maximum processor performance [7].

**Compilers and Libraries.** The compilers and libraries used in the experiments are listed in Table 2 and Table 3, respectively.

**Table 2: Compilers**

Compiler	Version
g++	14.2.0
Intel icpx	2025.1.1
NVIDIA nvc++	25.3-0

**Table 3: Libraries**

Library	Version
oneDPL	2022.8
TBB	2022.1
HPX	1.9.1
NVOMP	25.3
CUDA	12.8

### 4 Experiment Details

All aspects of the original pSTL-Bench experiments are replicated in this work, with one exception: the problem size in certain experiments is reduced from  $2^{30}$  to  $2^{29}$ . This adjustment was necessary

due to runtime crashes encountered by the oneDPL backend when using the larger problem size. The corresponding error message is shown in Listing 1.

**Listing 1: oneDPL GPU runtime error output**

```
<CUDA>[ERROR]:
UR CUDA ERROR:
  Value:                2
  Name:                  CUDA_ERROR_OUT_OF_MEMORY
  Description:           out of memory
  Function:               allocateMemObjOnDeviceIfNeeded
  Source Location:        /builds/oneapi-core/oneapi-release-
                        ↪ package/intel-llvm-mirror/build/_deps/unified-
                        ↪ runtime-src/source/adapters/cuda/memory.cpp:442

<CUDA>[ERROR]:
UR CUDA ERROR:
  Value:                2
  Name:                  CUDA_ERROR_OUT_OF_MEMORY
  Description:           out of memory
  Function:               allocateMemObjOnDeviceIfNeeded
  Source Location:        /builds/oneapi-core/oneapi-release-
                        ↪ package/intel-llvm-mirror/build/_deps/unified-
                        ↪ runtime-src/source/adapters/cuda/memory.cpp:442

terminate called after throwing an instance of 'sycl::_V1
                        ↪ ::exception'
what():  Native API failed. Native API returns: 38 (
                        ↪ UR_RESULT_ERROR_OUT_OF_HOST_MEMORY)
```

### 5 Experimental Results

This section presents the results of experiments designed to evaluate the performance of parallel STL algorithms across various compiler-backend combinations. While each experiment references the original results from the pSTL-Bench paper, those plots are not reproduced here. Readers are encouraged to consult the original publication for direct visual comparisons.

All plots presented in this work were generated using the R scripts available in the forked repository. Figures were exported at a resolution of 300 DPI to preserve detail and support zooming without quality loss.

The compiler names used in the plots differ from those in the original pSTL-Bench paper, as they are directly generated by the benchmarking tool. These names can be mapped to their original counterparts as follows:

- *GNU-OMP* corresponds to *GCC-GNU*.
- *GNU-\** corresponds to *GCC-\**.
- *IntelLLVM-TBB* corresponds to *ICC-TBB*.
- *NVHPC-\** corresponds to *NVC-\**.

To maintain consistency, the structure and subsection titles align with those of the original work.

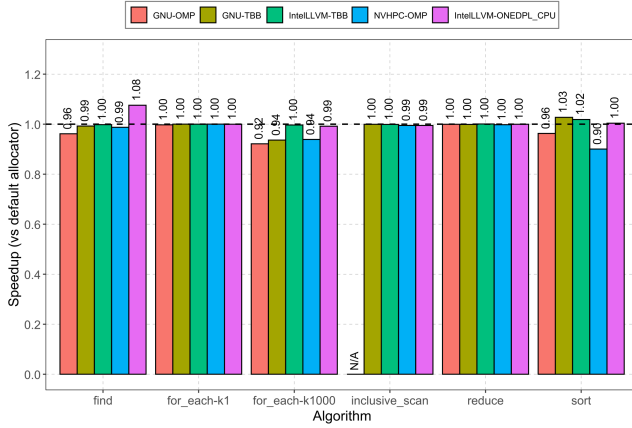
#### 5.1 The Impact of Memory Allocation

The first experiment investigates the effect of the custom memory allocator used in pSTL-Bench on the performance of parallel STL algorithms. Whereas the original study employed a problem size of  $2^{30}$ , this setup uses a reduced size of  $2^{29}$ , as described in Section 4.

In the original paper, the custom allocator demonstrated significant performance improvements—particularly for the *for\_each* and *reduce* algorithms—achieving speedups of up to 1.5x over the default allocator.

In this evaluation, no substantial performance difference was observed between the custom and default allocators. The measured results are presented in Figure 1.

Despite the minimal performance impact in this setting, the custom allocator was retained to ensure consistency with the methodology of the original study.



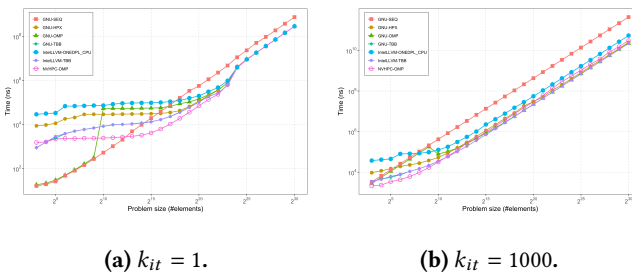
**Figure 1: Speedup when using custom parallel allocator with 32 threads and a problem size of  $2^{29}$ . Higher is better.**

## 5.2 X::for\_each

This experiment evaluates the performance of the *for\_each* algorithm. The parameter  $k_{it}$  represents the arithmetic intensity of the workload. For higher values of  $k_{it}$ , performance is expected to approach ideal speedup.

Figure 2 presents the execution time for *for\_each* with minimal and maximal  $k_{it}$  values. The results closely resemble those reported in the original pSTL-Bench paper. For  $k_{it} = 1$ , the NVIDIA OpenMP backend achieves the best performance. In contrast, for  $k_{it} = 1000$ , all backends exhibit comparable execution times.

The oneDPL backend on CPU consistently performed worse than the other backends across both configurations.



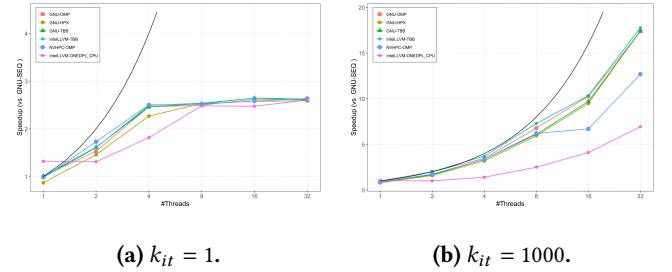
(a)  $k_{it} = 1$ .

(b)  $k_{it} = 1000$ .

**Figure 2: Results for benchmark X::for\_each. Problem size scaling using all cores except for the GNU-SEQ implementation. Lower is better.**

Figure 3 shows the strong scaling results for the *for\_each* algorithm with  $2^{29}$  elements. Compared to the original paper, the results differ slightly. In the original study, all backends achieved ideal speedup for  $k_{it} = 1000$  and near-ideal speedup for  $k_{it} = 1$ .

In this evaluation, the oneDPL backend on CPU underperforms relative to the others. Additionally, all backends begin to lose scalability beyond 8 threads, which is likely due to the hardware architecture—specifically, the presence of 8 performance cores (P-cores) and 16 efficiency cores (E-cores).



(a)  $k_{it} = 1$ .

(b)  $k_{it} = 1000$ .

**Figure 3: Results for benchmark X::for\_each. Strong scaling with  $2^{29}$  elements. Higher is better.**

## 6 Conclusions

Here you need to summarize what you did and why this is important. Do not take the abstract and put it in the past tense. Remember, now the reader has (hopefully) read the report, so it is a very different situation from the abstract. Try to highlight important results and say the things you really want to get across such as high-level statements (e.g., we believe that .... is the right approach to .... Even though we only considered x, the .... technique should be applicable ....) You can also formulate next steps if you want. Be brief. After the conclusions there are only the references.

## References

- [1] R. Laso, D. Krupitza, and S. Hunold, "Exploring Scalability in C++ Parallel STL Implementations" in *Proceedings of the 53rd International Conference on Parallel Processing (ICPP '24)*, Association for Computing Machinery, New York, NY, USA, 2024, pp. 284–293. <https://doi.org/10.1145/3673038.3673065>
- [2] W.-C. Lin, T. Deakin, and S. McIntosh-Smith, "Evaluating ISO C++ Parallel Algorithms on Heterogeneous HPC Systems" in *2022 IEEE/ACM International Workshop on Performance Modeling, Benchmarking and Simulation of High Performance Computer Systems (PMBS)*, Dallas, TX, USA, 2022, pp. 36–47. <https://doi.org/10.1109/PMBS56514.2022.00009>
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