

Benchmark Results Report

This report summarizes the benchmark analysis of VectorTree by comparing its performance with:

1. `std::vector`
2. a primitive persistent vector

VectorTree is created to obtain a persistent version of `std::vector` for multithreaded usage. In other words, the target of VectorTree is to achieve the performance of `std::vector` while keeping the persistency to deal with the concurrency issues. Hence, the 1st container to compare with is `std::vector`. The 2nd one is a primitive definition for a persistent vector. The flowchart of any operation on the primitive persistent vector is as follows:

1. create a copy of the original vector,
2. apply the request on the copy,
3. return the modified copy.

Four fundamental operations are inspected in this benchmark:

1. `emplace_back`
2. `pop_back`
3. `pop_front`
4. `traversal`

The 3rd operation is actually not a property of the vector data structure such that `std::vector` interface does not include it. It requires one-step move operation on all elements which is linear, $O(N)$. Its the same, even more problematic, in case of a tree of vectors. `VectorTree` solves this problem using swap-and-pop idiom while loosing the order of elements. Hence, the `pop_front` graphs showing a better performance for `VectorTree`, actually shows the performance support coming from the swap-and-pop idiom. In other words, consider the graphs for the `pop_front` operation as the comparison between:

- `pop_front`: `move<T>` with $O(N)$
- swap-and-pop: `front() = back(); pop_back(); copy<T>` with $O(2*BufferSize)$

Summary of the test parameters:

1. Inspected operations: `emplace_back`, `pop_back`, `pop_front` and `traversal`
2. Inspected objects: Two types are inspected: `type_small` and `type_large`
3. Original container size:
 - `BUFFER_SIZE_1` (32)
 - `BUFFER_SIZE_2` (1024)
 - `BUFFER_SIZE_3` (32768)

The two object types are defined simply as follows:

1. `type_small`: an object with one field of `int`
2. `type_large`: an object with an array of 256 elements of `int`

The number of the combinations of the test parameters are:

1. # of the inspected operations: 4
2. # of the inspected objects: 2
3. # of the inspected original container sizes: 3

Hence, the combination of the test parameters yield:

$$\text{Test count} = 4 * 2 * 3 = 24$$

Note that the tests are performed with a `VectorTree` of buffer size of 32.

The tests follow a simple algorithm:

1. Initialize a container with a predefined size, N
2. Apply the operation iteratively N times on this original container
3. Measure timing

A templated wrapper class is created to simulate a uniform interface for the inspected four operations which helps to simplify the google benchmark macros. A base template (VectorTree) and two specializations (std::vector and persistent_vector) simulate the three containers to be compared.

DEFINE_BENCHMARK macro defines a shortcut to the google benchmark macros.

The tests are quite simple and the corresponding graphs are self-explanatory. Hence, i will not go through the results in detail.

In summary:

- For containers of small size, although VectorTree is the worst one, it performs efficiently (~600ms):
 - > See graphs with BUFFER_SIZE_1
- For containers of large size, VectorTree performs way better than the primitive persistent vector:
 - > See graphs with BUFFER_SIZE_3
- VectorTree approaches to std::vector in case of the three fundamental operations:
 - > See graphs with BUFFER_SIZE_3 and especially with type_large
- The swap-and-pop idiom provides an efficient solution to the pop_front operation:
 - > See graphs with pop_front

- The most important problem of VectorTree is the traversal performance. A traversal with a VectorTree of size=32768 takes around ~0.01 seconds which may be unacceptable in some cases:
 - > See Figures 21 and 24

The iterator must step to the next leaf node when the end of the current leaf node buffer is reached which requires a DFS algorithm within the tree structure. The worst traversal performance is a result of the DFS algorithm abstracted/hidden by the `path_to_leaf_node__current` variable. Hence, the iterator of VectorTree must be improved.

I will study two approaches to either remove or improve the DFS:

1. Memoization (removes DFS):

VectorTree stores a linear container of pointers to the leaf node buffers,

2. Asynchronous approach (improves DFS):

A thread determines the next leaf node buffer asynchronously.

Both have pros and cons which must be studied in detail.

For example the memoization adds more memory load:

array of pointers of $N/32$ size where 32 is the buffer size.

Asynchronous approach, on the other hand, terminates the default copy capability of the iterator which reduces the copy construction performance.

The increment operator (i.e. `operator++(int)`) and the derivatives becomes ineffective as a result.

Figure 1: `emplace_back` | `type_large` | `DEFAULT_BUFFER_1`

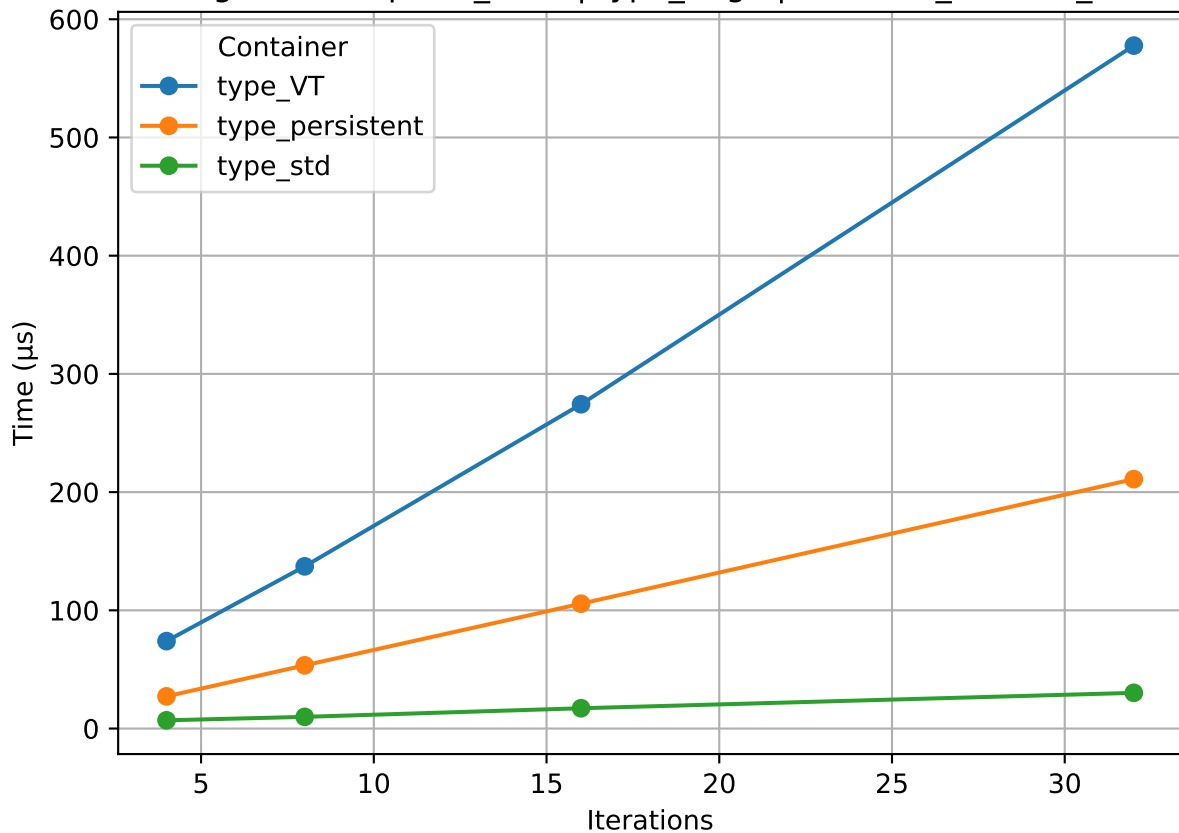
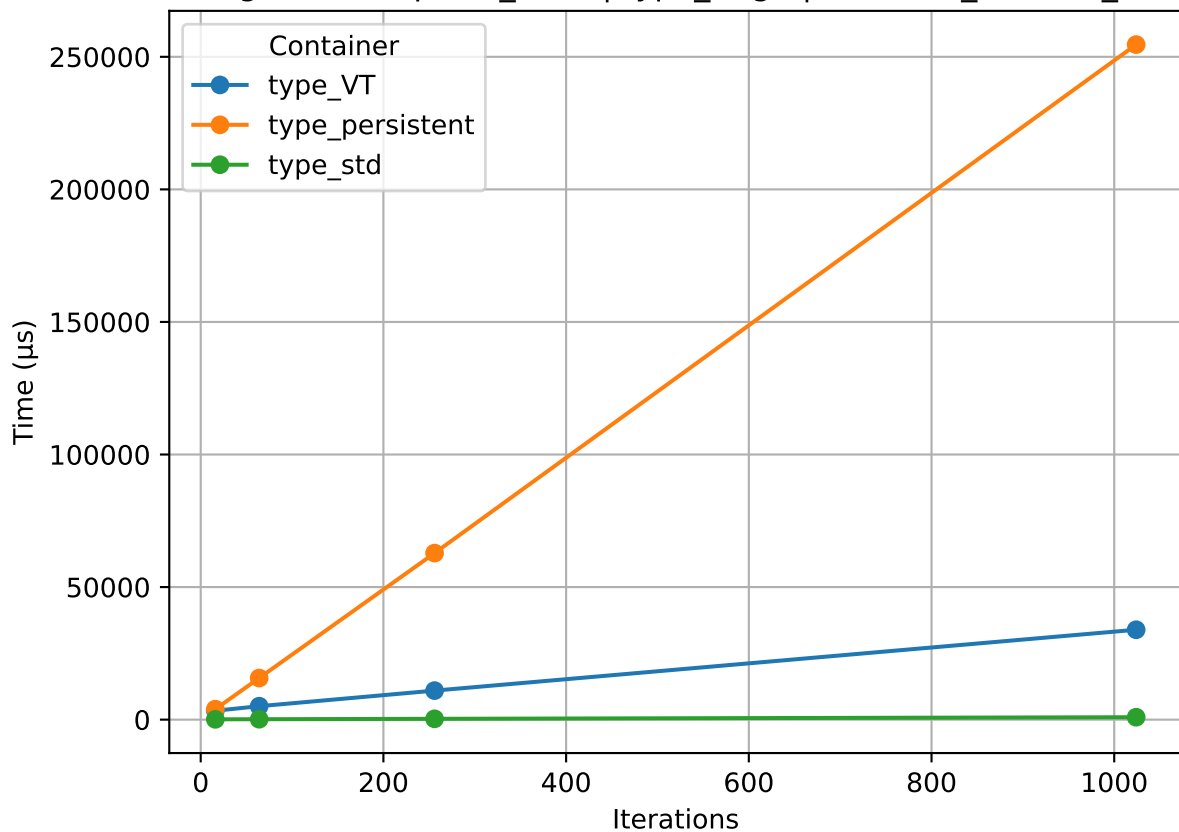


Figure 2: `emplace_back` | `type_large` | `DEFAULT_BUFFER_2`



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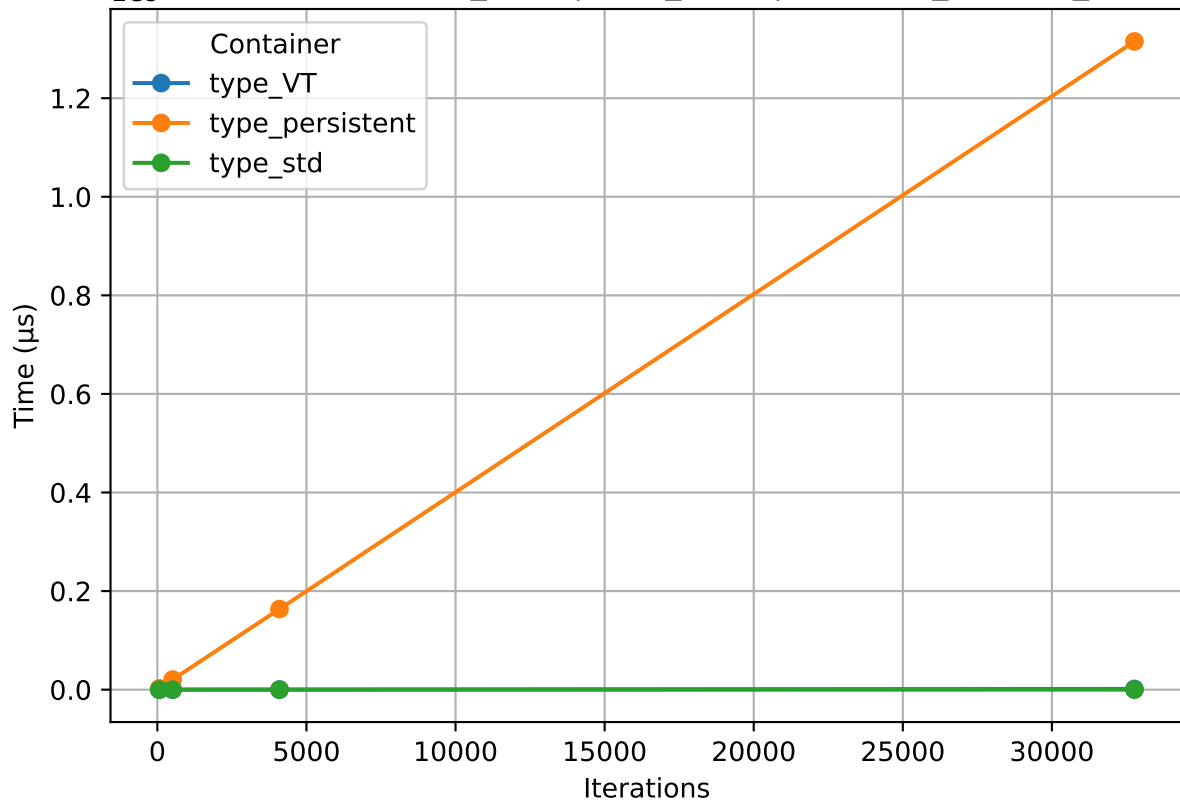


Figure 4: `emplace_back` | `type_small` | `DEFAULT_BUFFER_1`

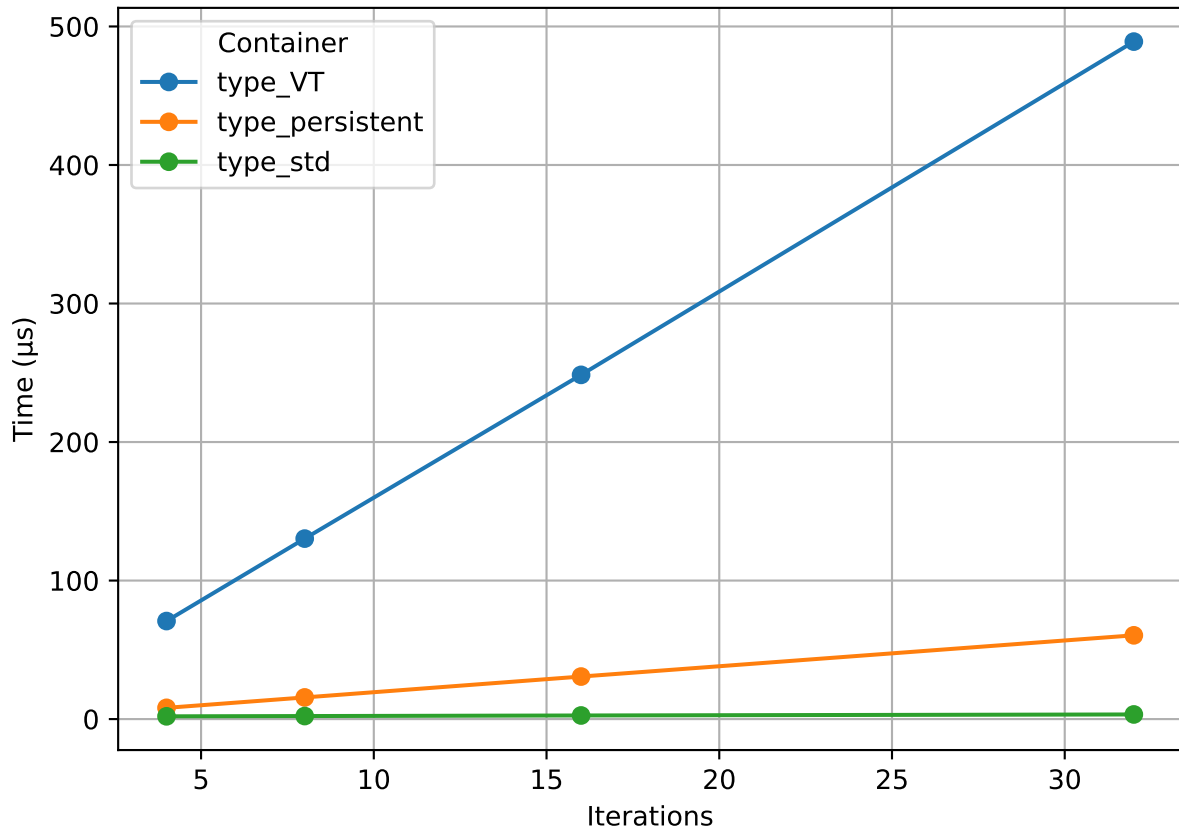


Figure 5: `emplace_back` | `type_small` | `DEFAULT_BUFFER_2`

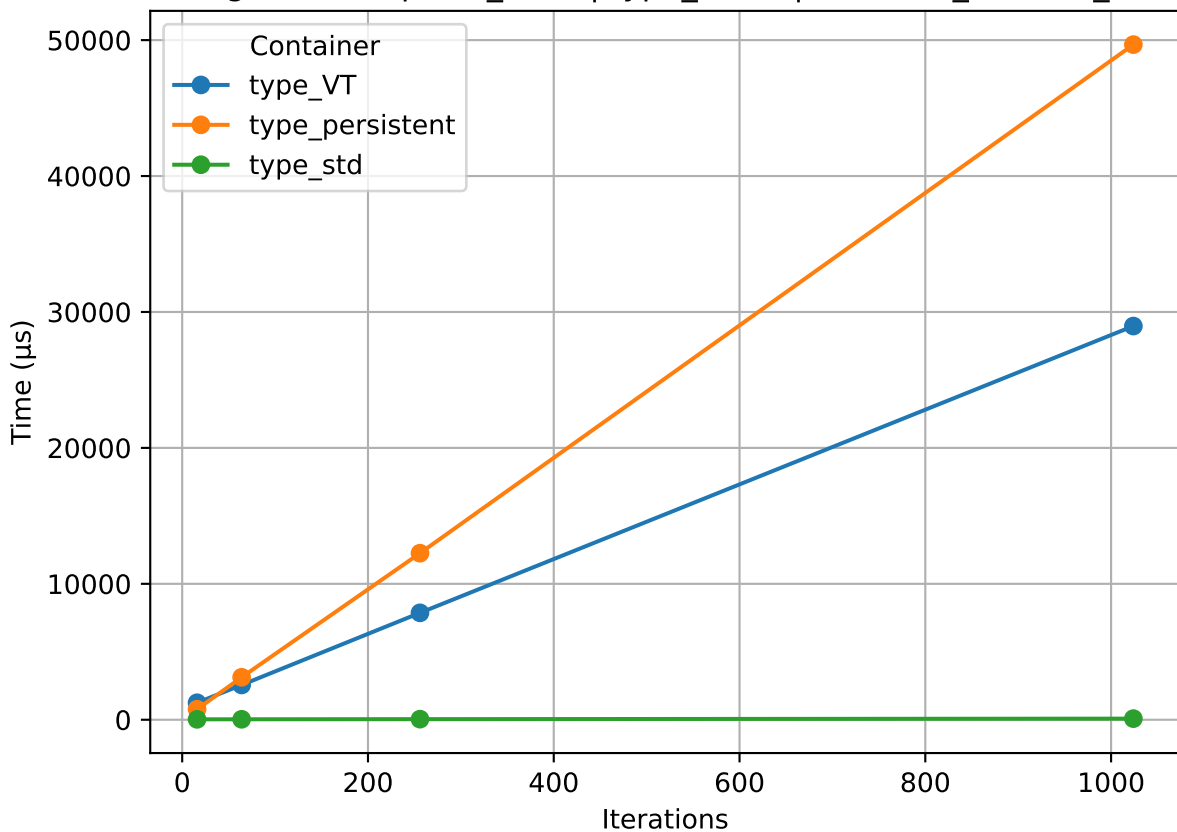


Figure 6: `emplace_back` | `type_small` | `DEFAULT_BUFFER_3`

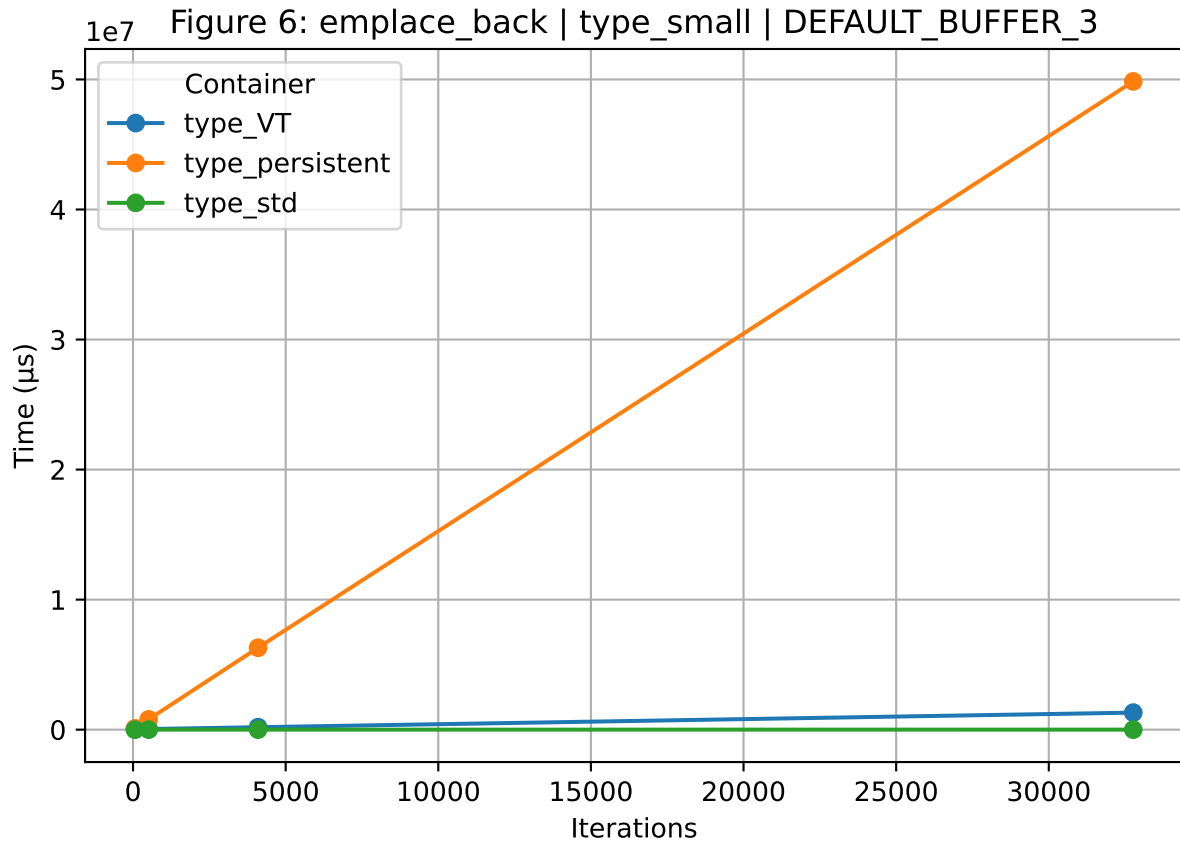


Figure 7: pop_back | type_large | DEFAULT_BUFFER_1

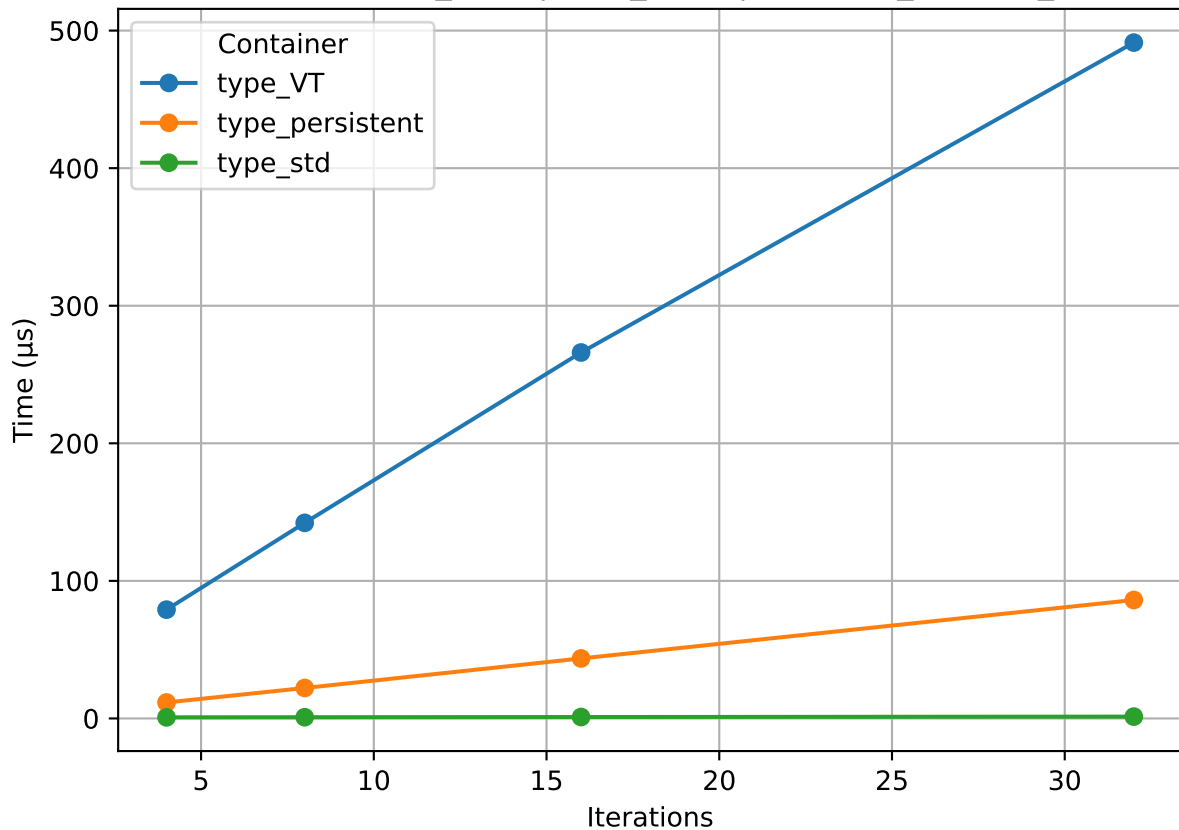


Figure 8: pop_back | type_large | DEFAULT_BUFFER_2

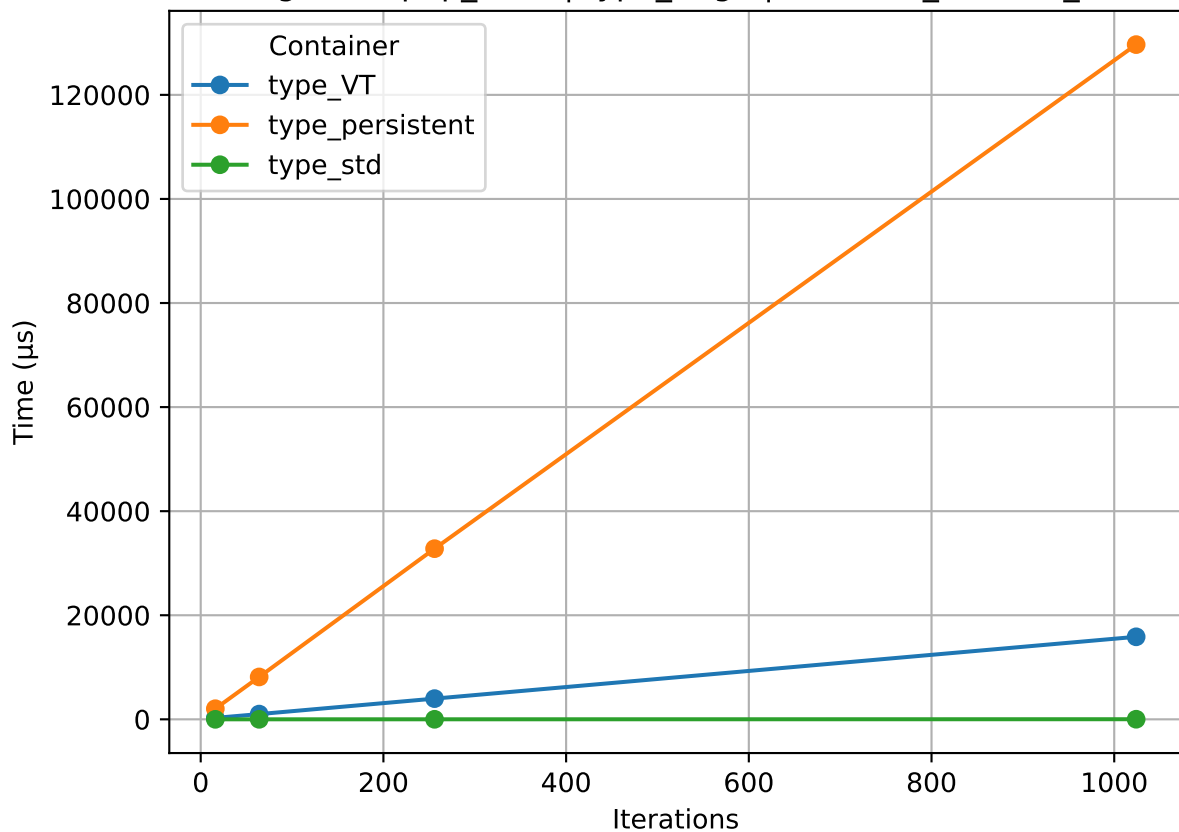


Figure 9: pop_back | type_large | DEFAULT_BUFFER_3

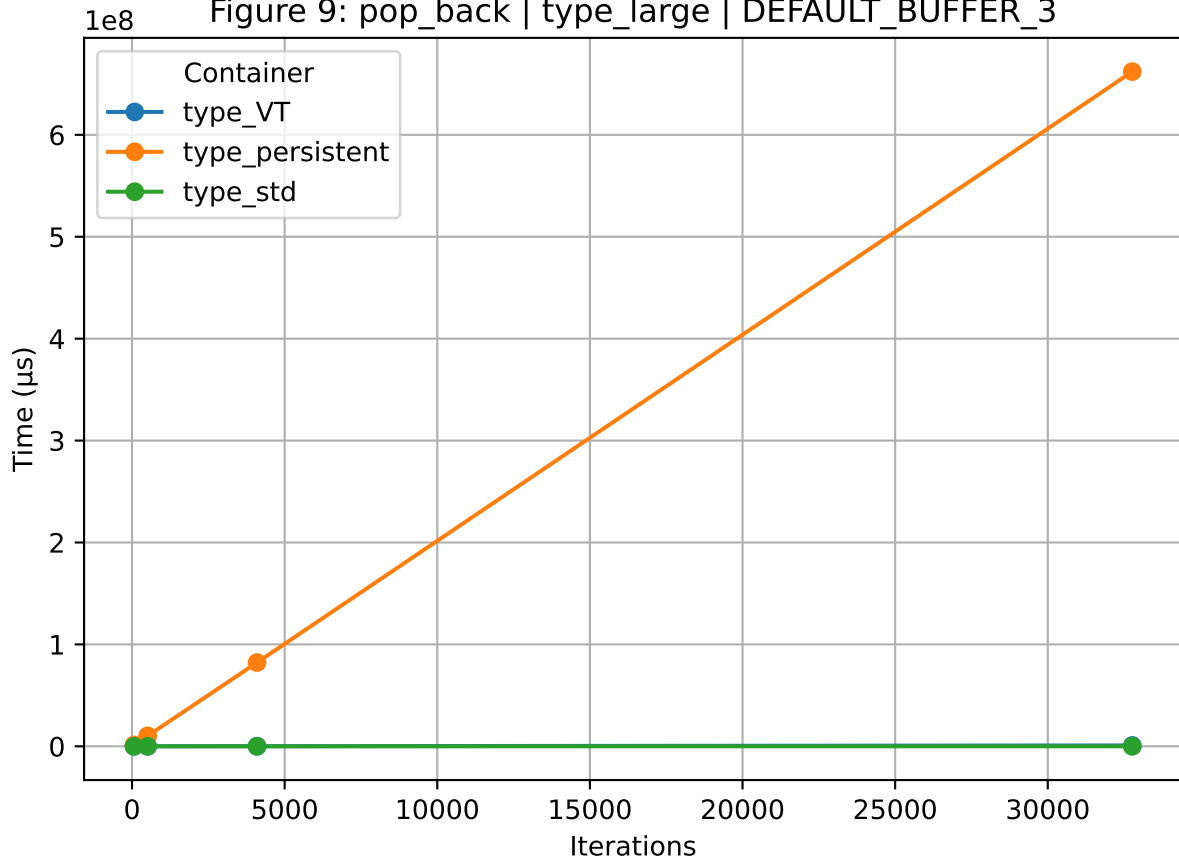


Figure 10: pop_back | type_small | DEFAULT_BUFFER_1

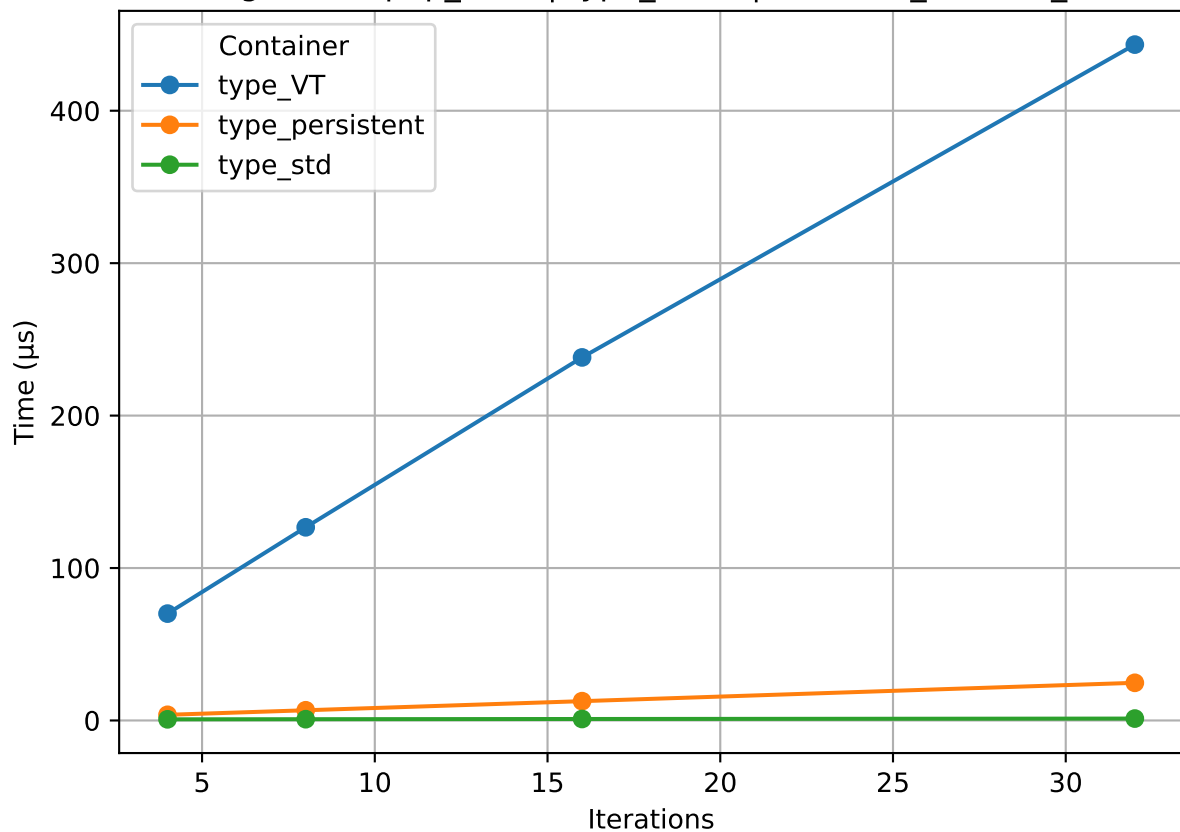


Figure 11: pop_back | type_small | DEFAULT_BUFFER_2

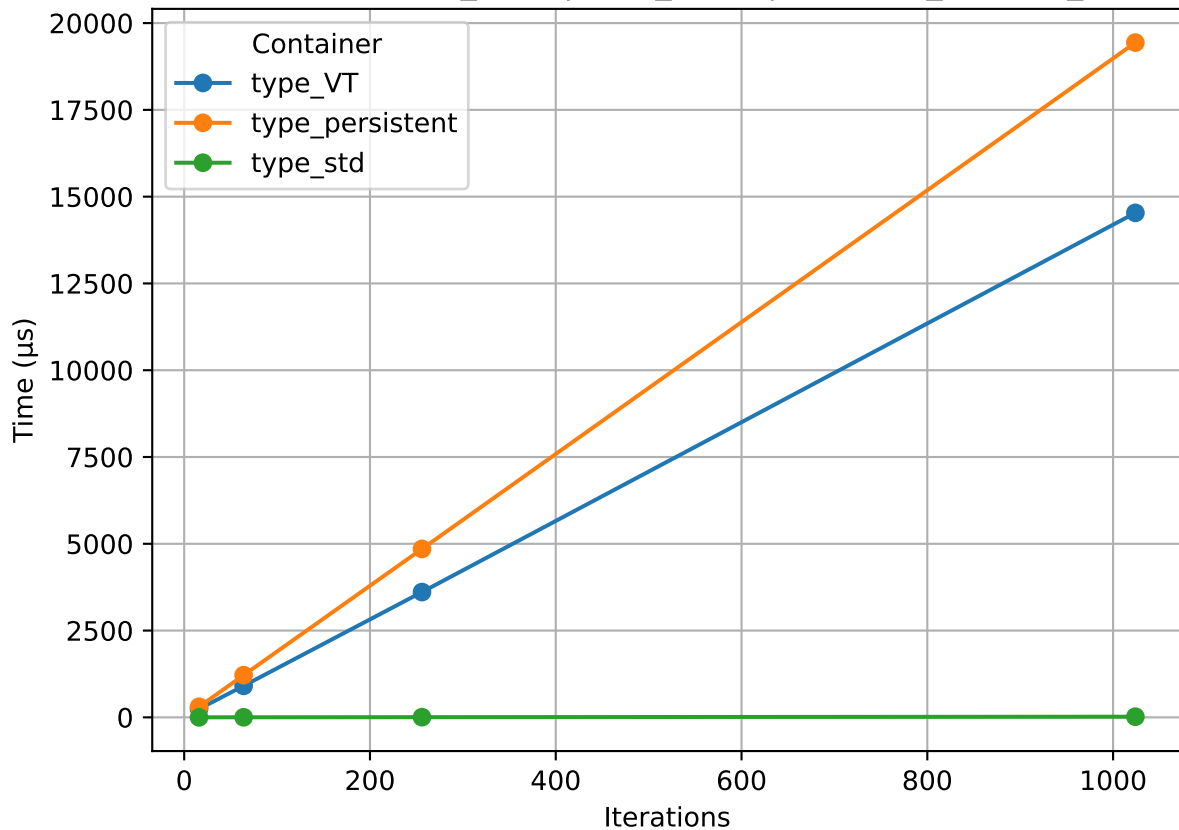


Figure 12: pop_back | type_small | DEFAULT_BUFFER_3

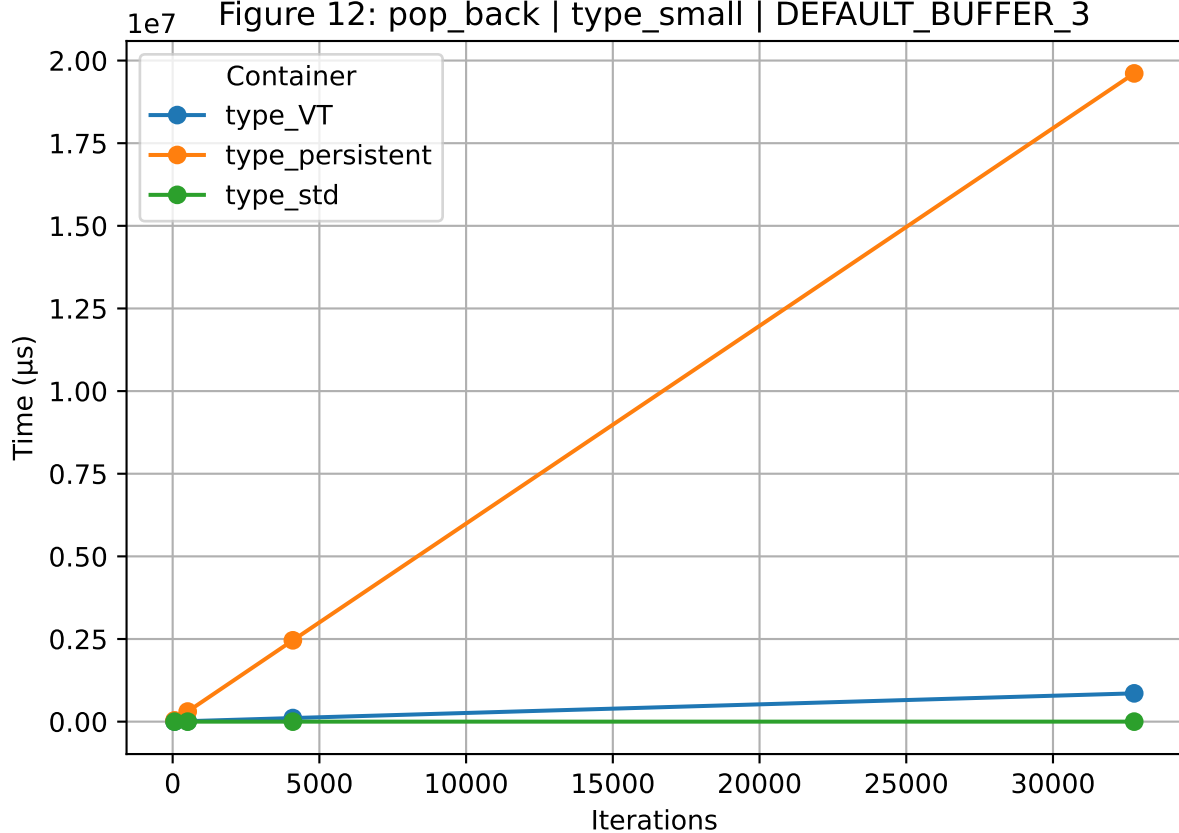


Figure 13: pop_front | type_large | DEFAULT_BUFFER_1

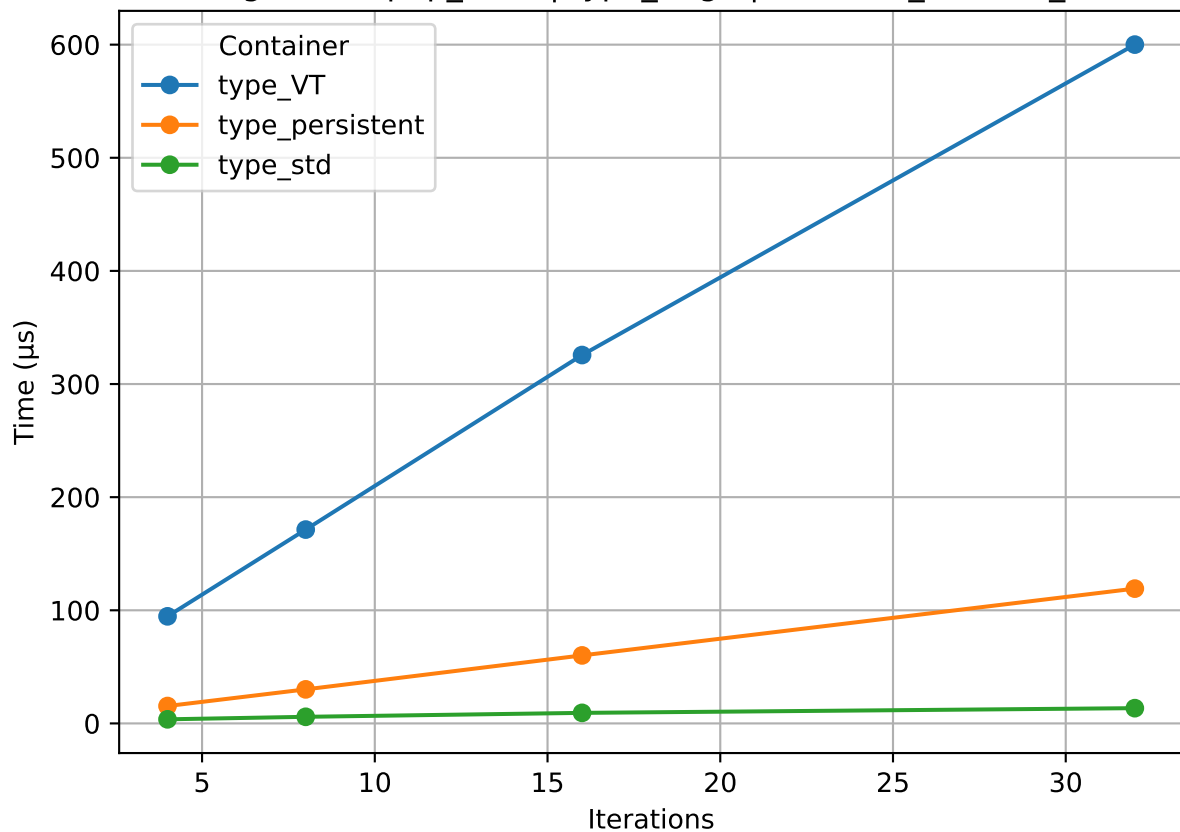


Figure 14: pop_front | type_large | DEFAULT_BUFFER_2

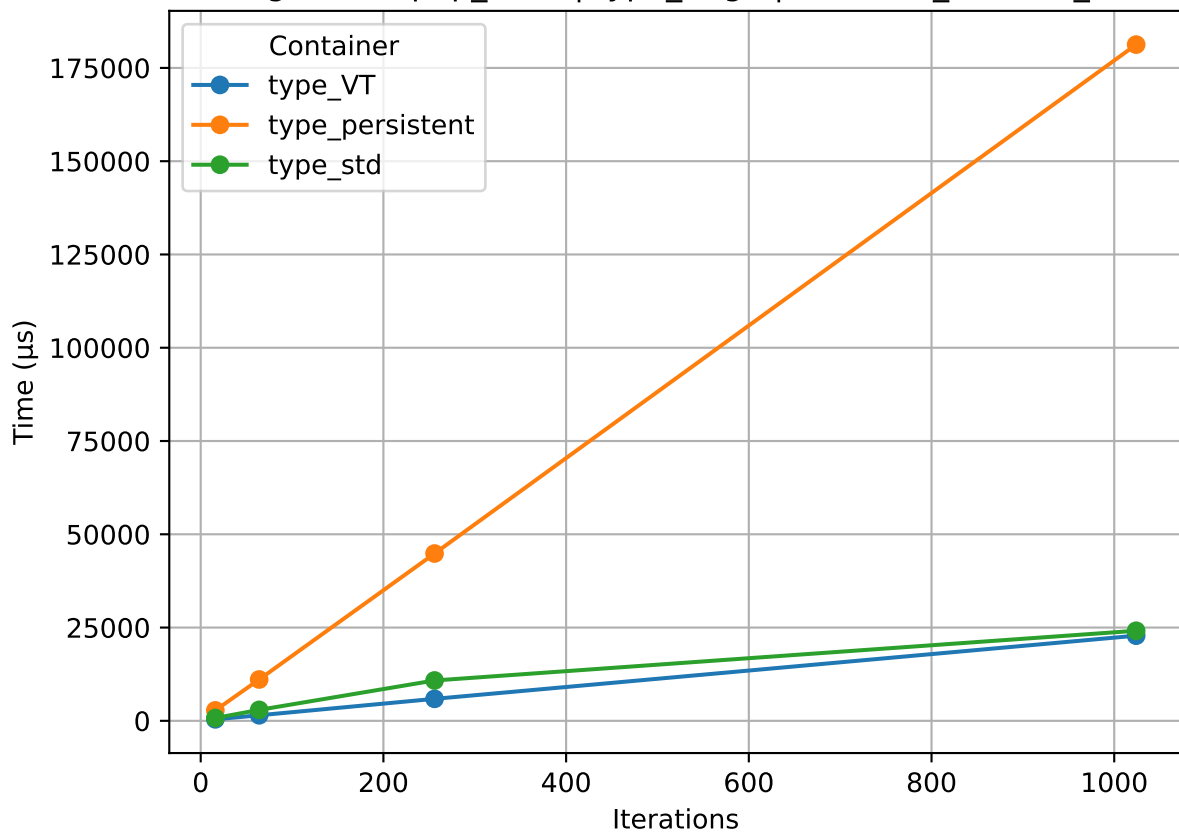


Figure 15: pop_front | type_large | DEFAULT_BUFFER_3

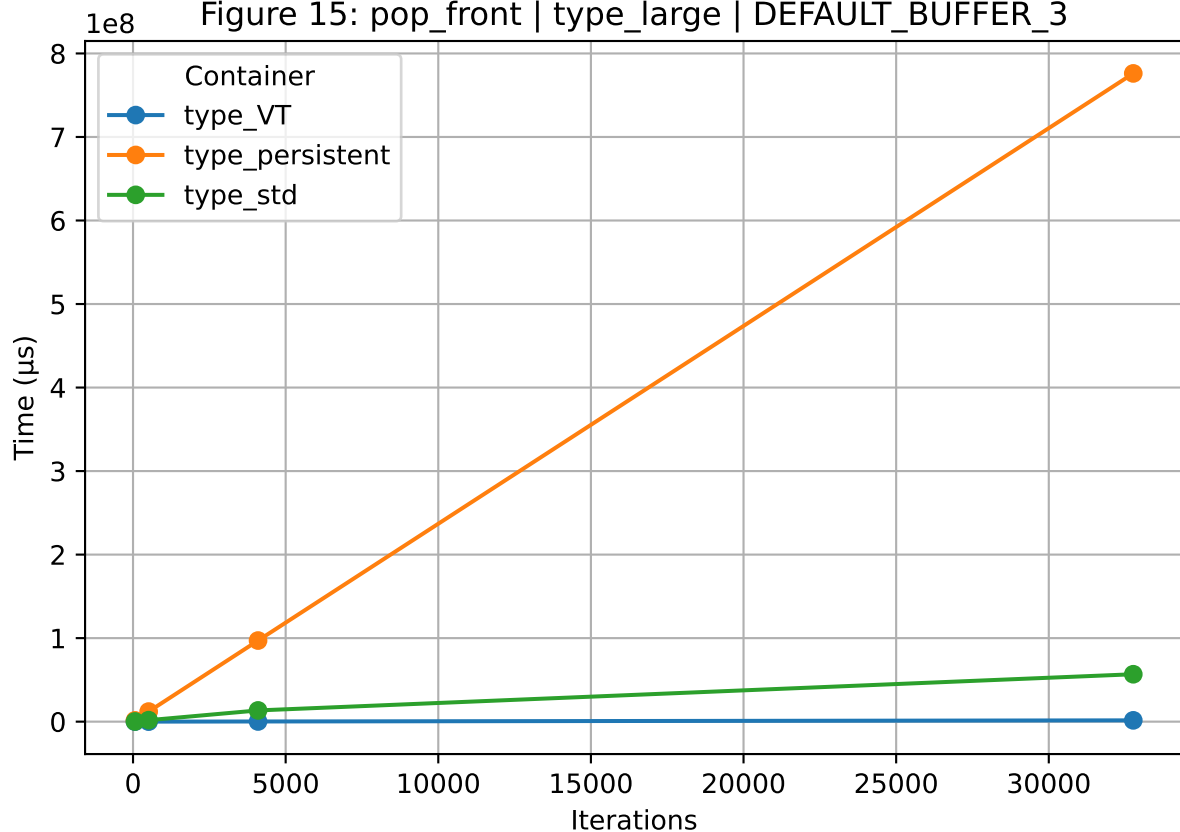


Figure 16: pop_front | type_small | DEFAULT_BUFFER_1

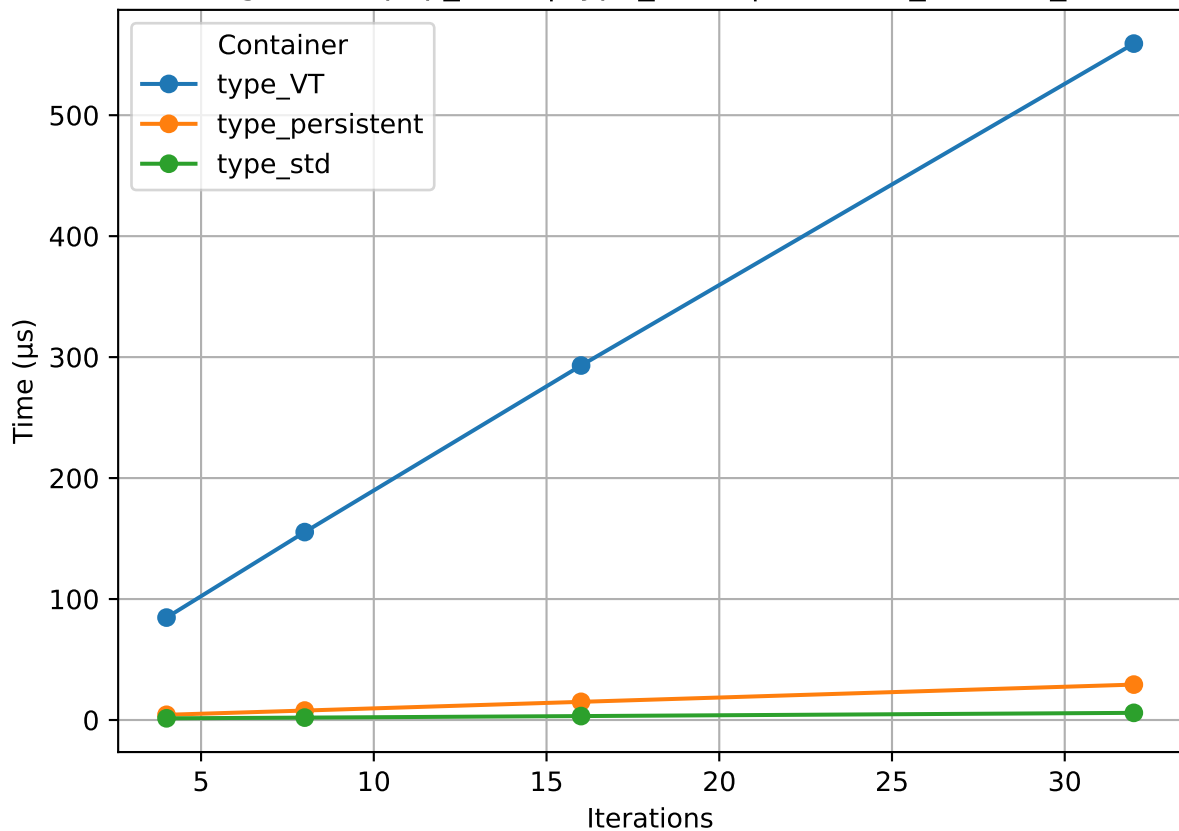
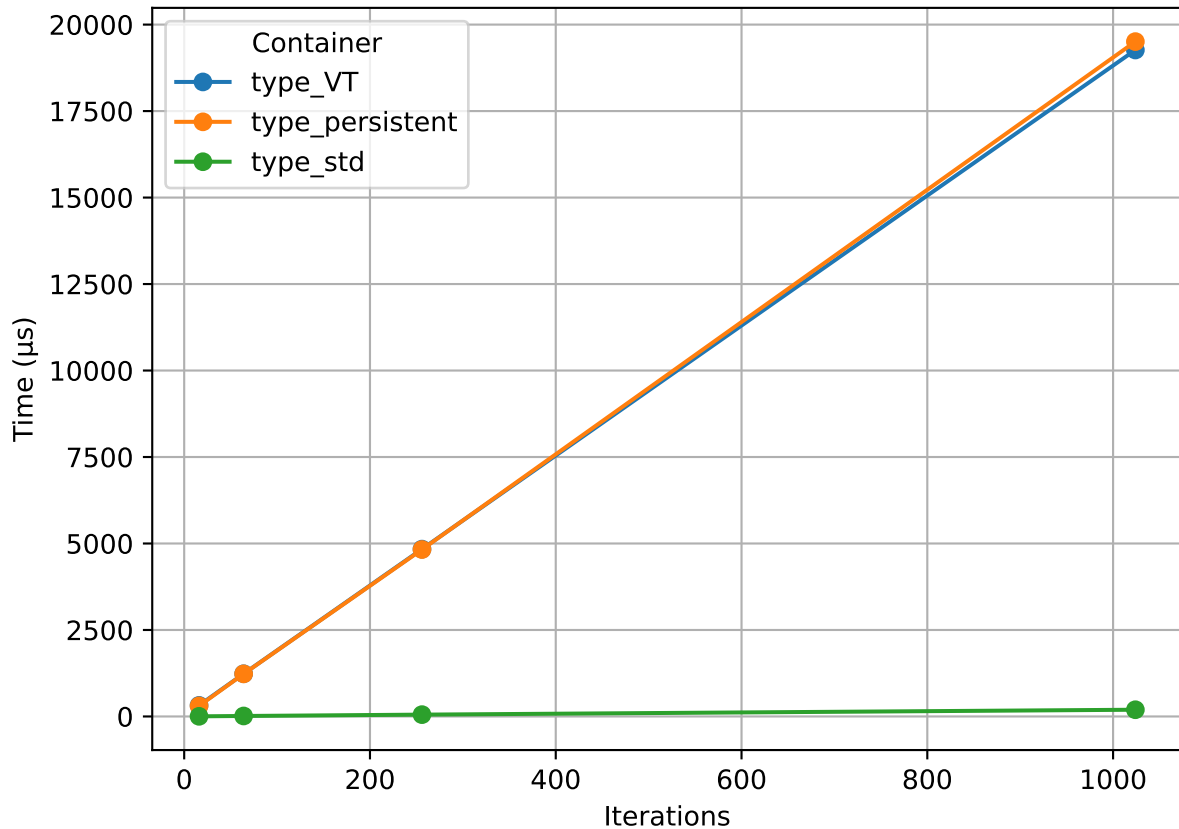


Figure 17: pop_front | type_small | DEFAULT_BUFFER_2



1e7 Figure 18: pop_front | type_small | DEFAULT_BUFFER_3

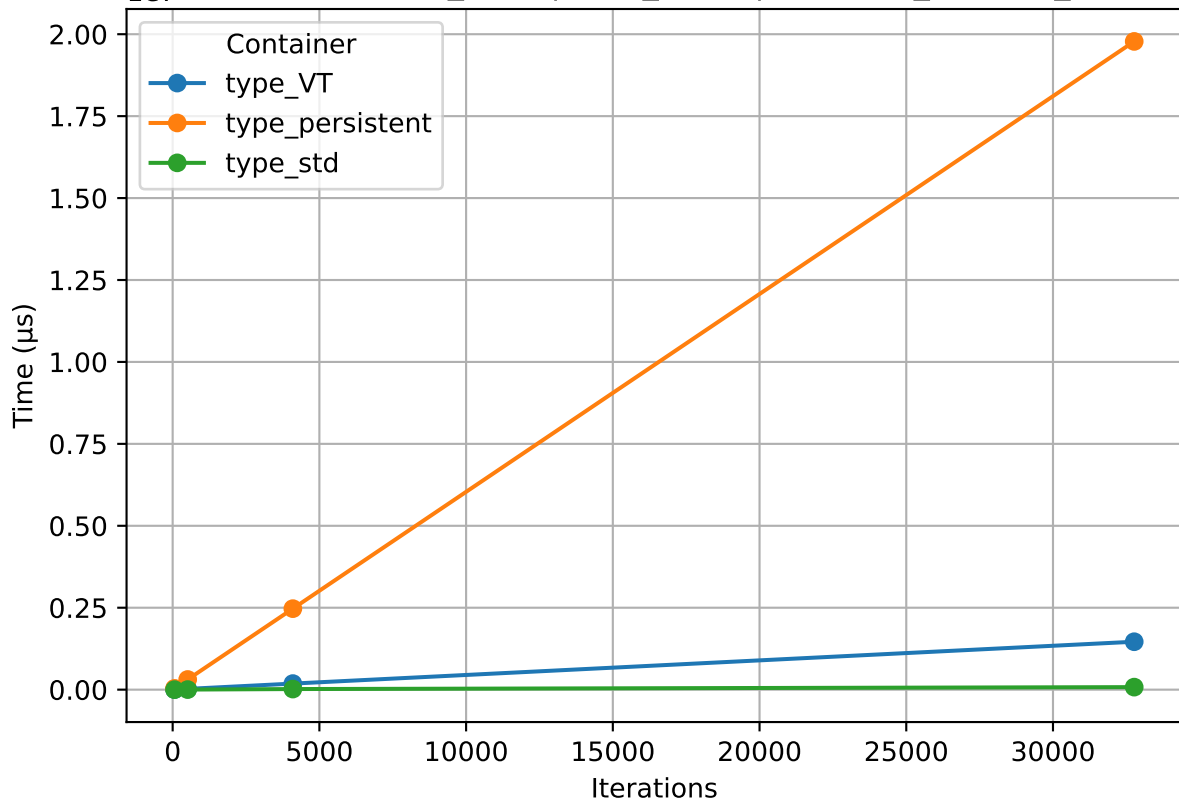


Figure 19: traversal | type_large | DEFAULT_BUFFER_1

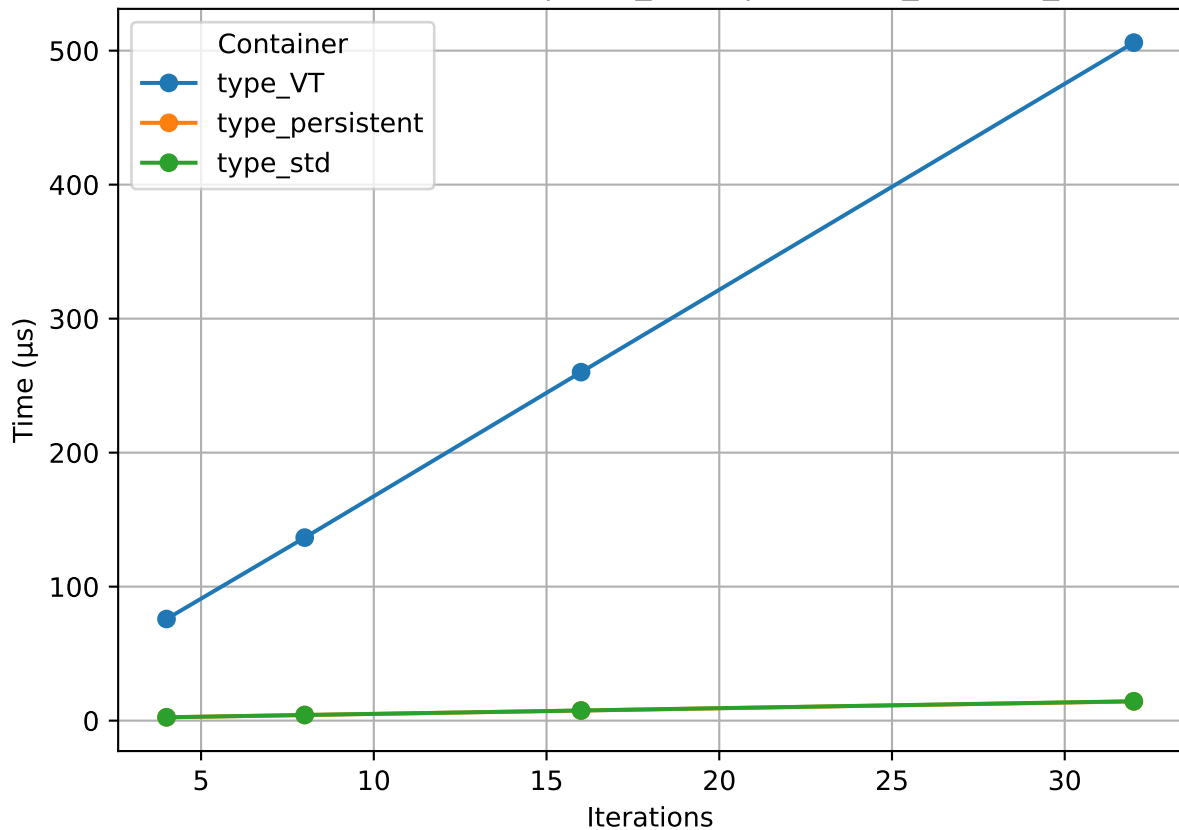


Figure 20: traversal | type_large | DEFAULT_BUFFER_2

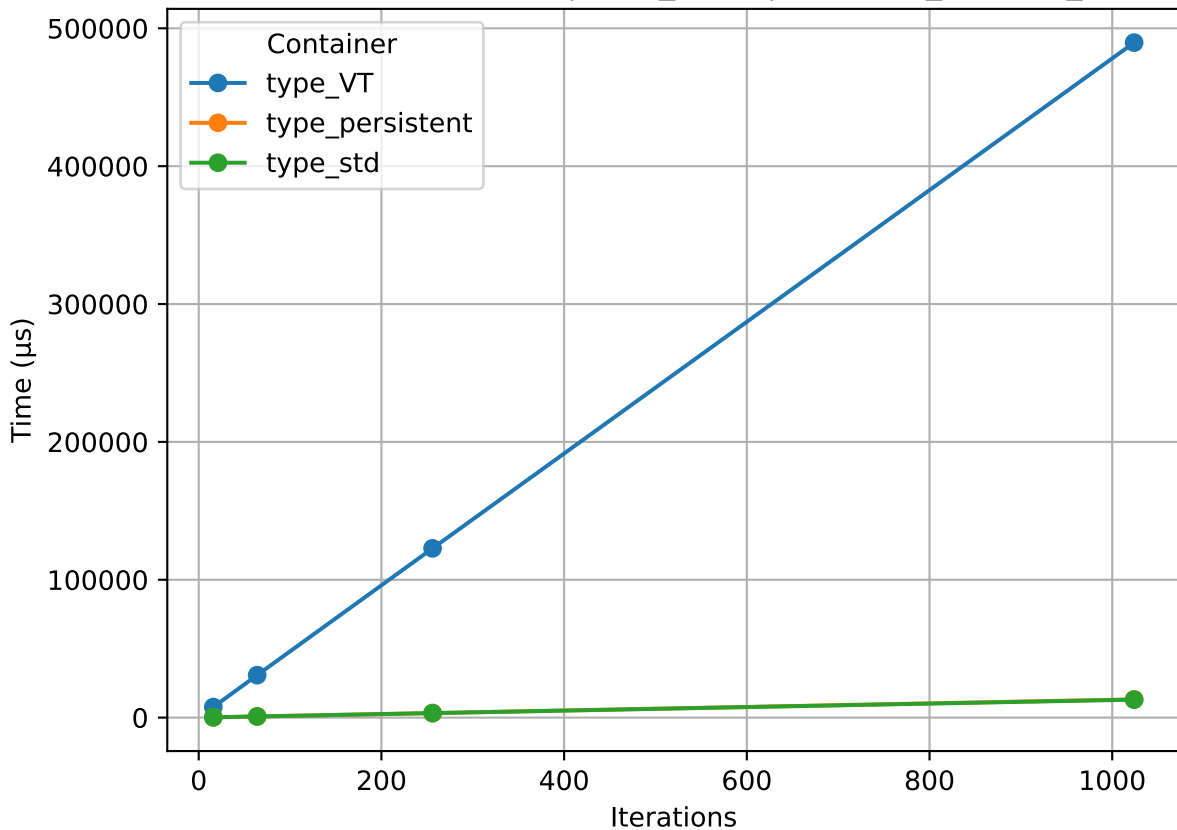


Figure 21: traversal | type_large | DEFAULT_BUFFER_3

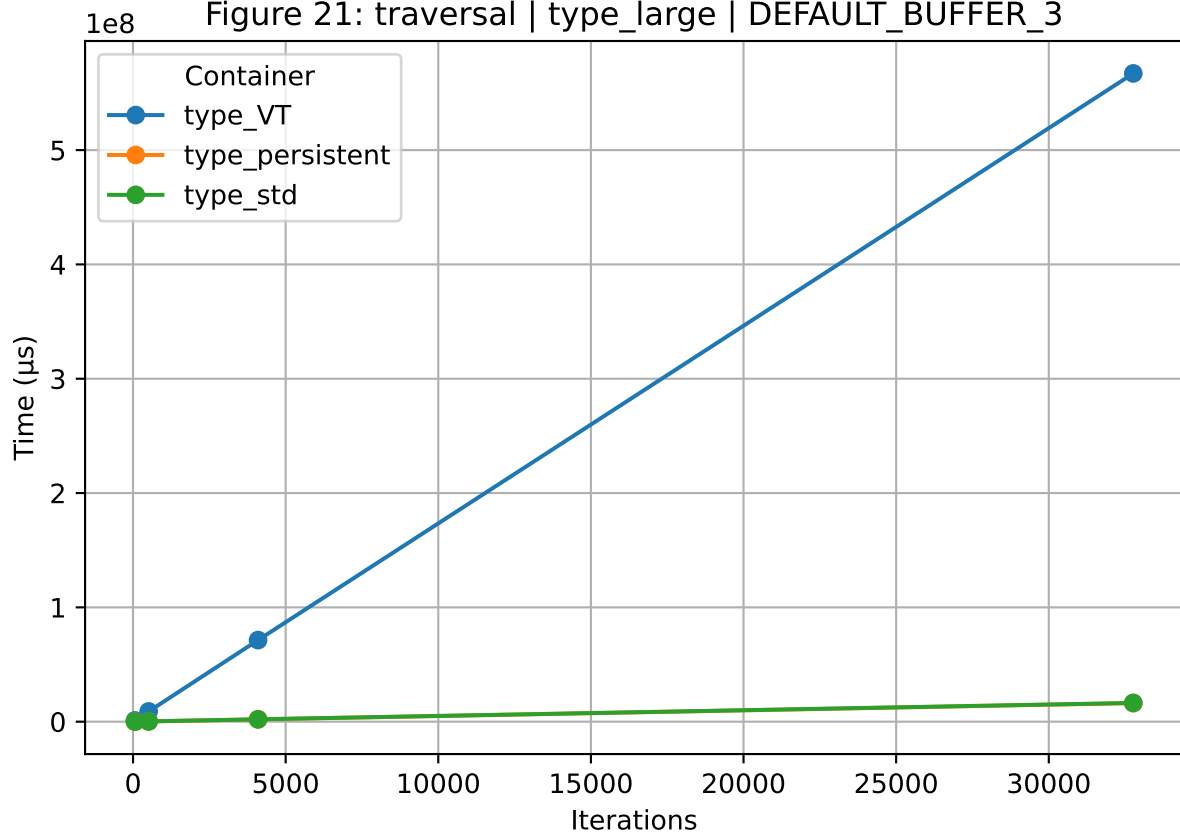


Figure 22: traversal | type_small | DEFAULT_BUFFER_1

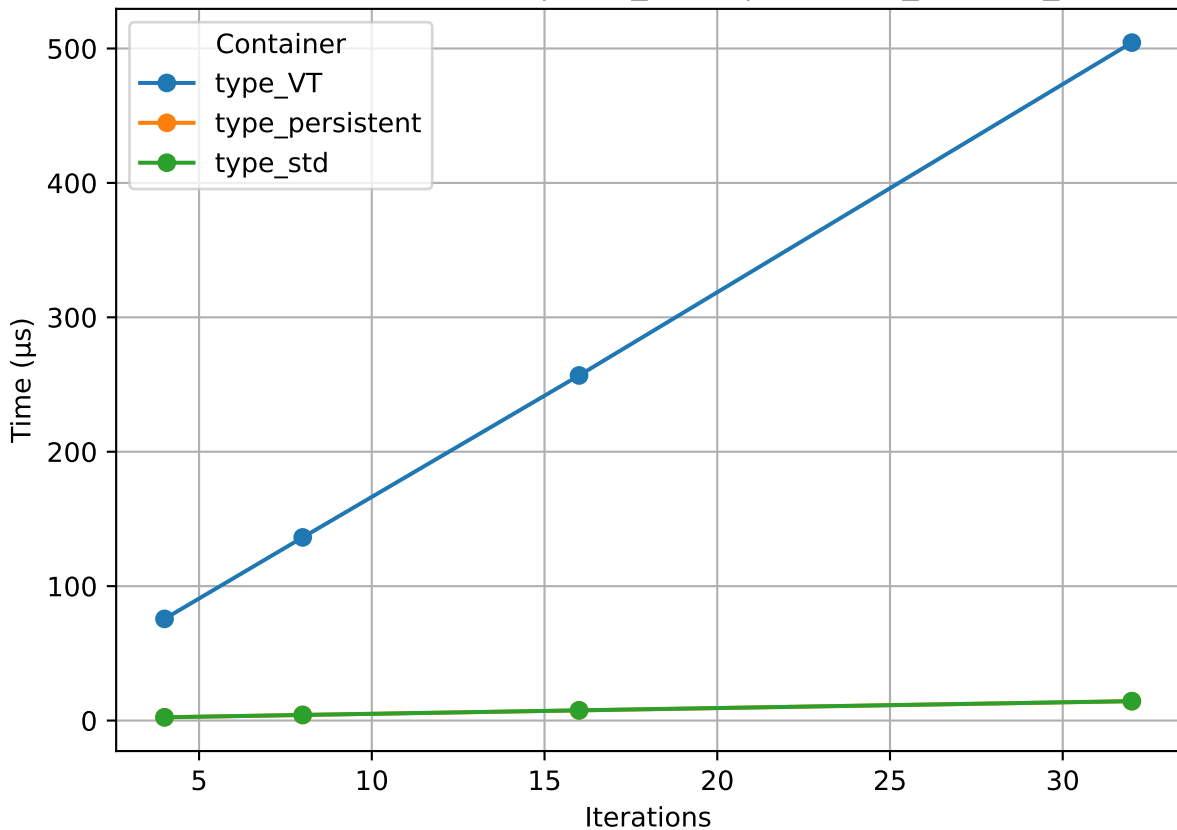


Figure 23: traversal | type_small | DEFAULT_BUFFER_2

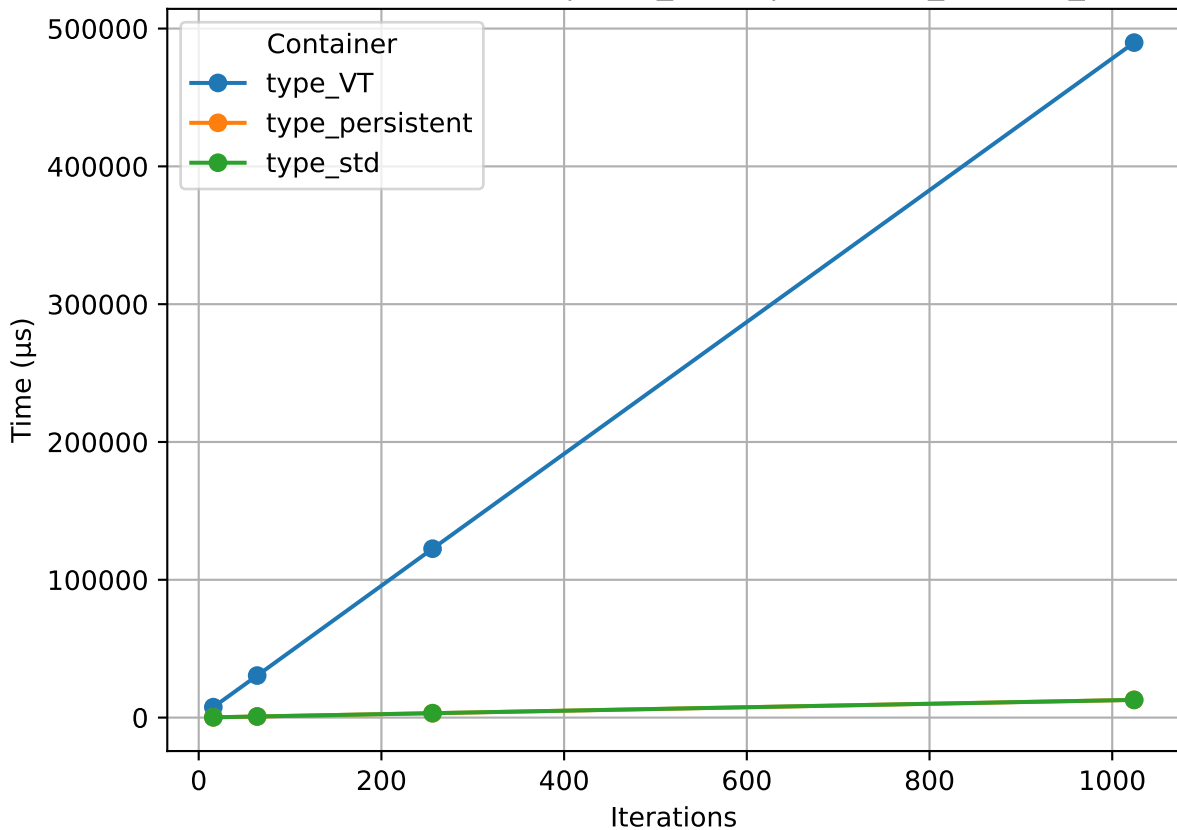


Figure 24: traversal | type_small | DEFAULT_BUFFER_3

