PDC REPORT

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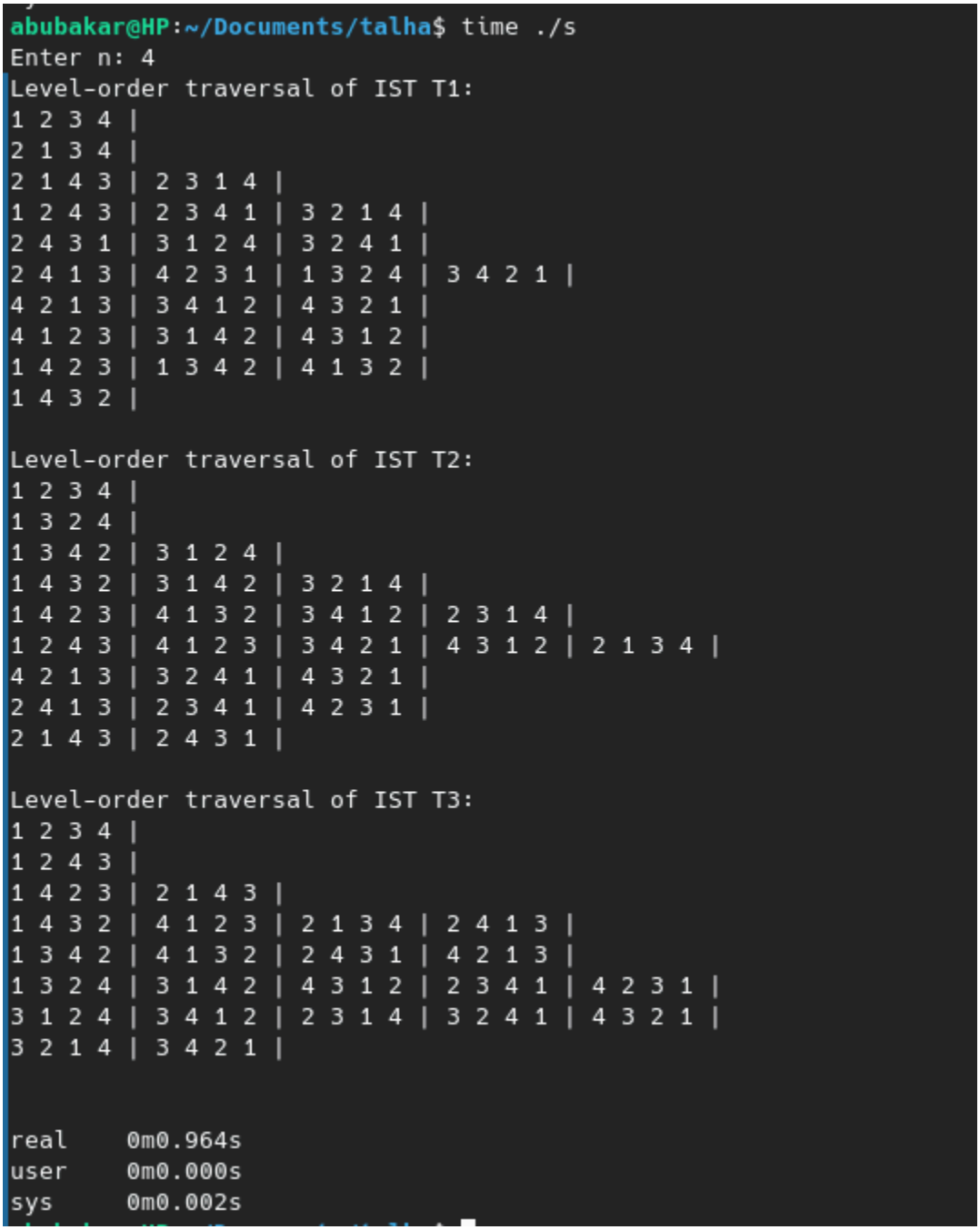
Sequential Performance:

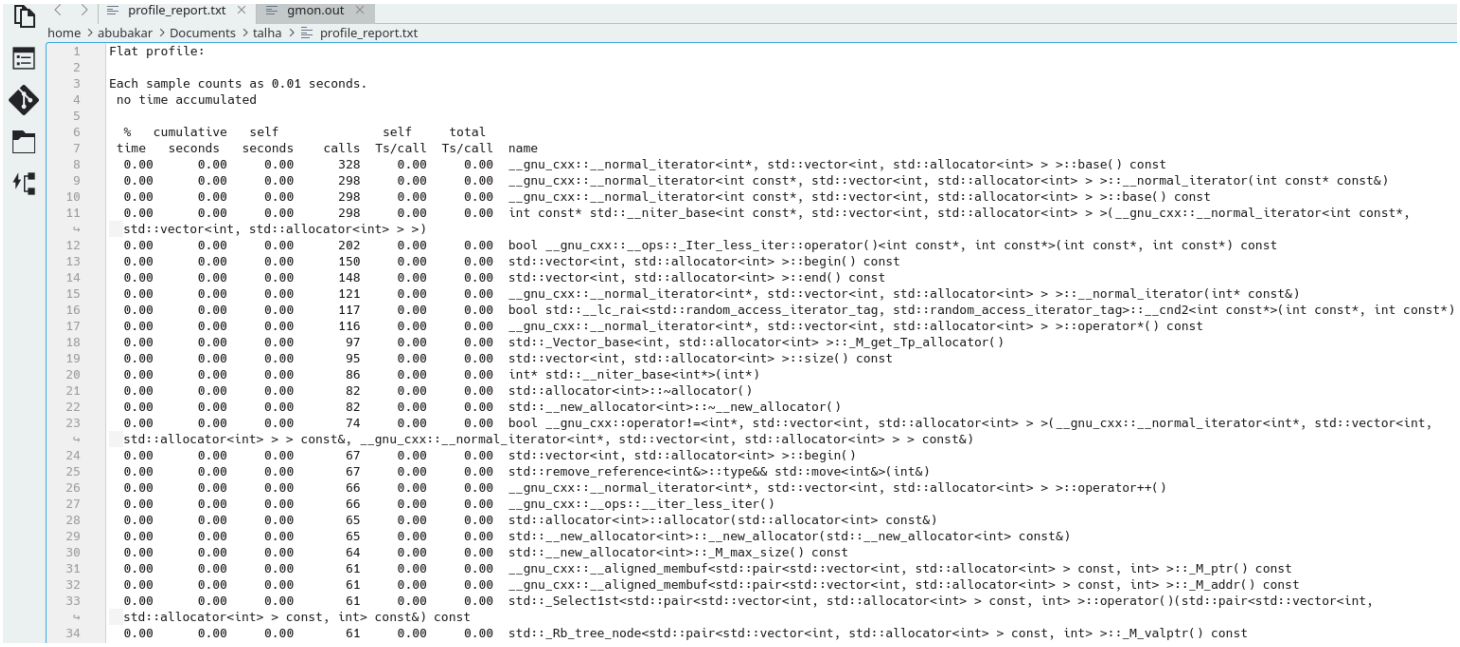


```
abubakar@HP:~/Documents/talha$ time ./s
Enter n: 4
Level-order traversal of IST T1:
1 2 3 4 |
2 1 3 4 |
2 1 4 3 | 2 3 1 4 |
1 2 4 3 | 2 3 4 1 | 3 2 1 4 |
2 4 3 1 | 3 1 2 4 | 3 2 4 1 |
2 4 1 3 | 4 2 3 1 | 1 3 2 4 | 3 4 2 1 |
4 2 1 3 | 3 4 1 2 | 4 3 2 1 |
4 1 2 3 | 3 1 4 2 | 4 3 1 2 |
1 4 2 3 | 1 3 4 2 | 4 1 3 2 |
1 4 3 2 |

Level-order traversal of IST T2:
1 2 3 4 |
1 3 2 4 |
1 3 4 2 | 3 1 2 4 |
1 4 3 2 | 3 1 4 2 | 3 2 1 4 |
1 4 2 3 | 4 1 3 2 | 3 4 1 2 | 2 3 1 4 |
1 2 4 3 | 4 1 2 3 | 3 4 2 1 | 4 3 1 2 | 2 1 3 4 |
4 2 1 3 | 3 2 4 1 | 4 3 2 1 |
2 4 1 3 | 2 3 4 1 | 4 2 3 1 |
2 1 4 3 | 2 4 3 1 |

Level-order traversal of IST T3:
1 2 3 4 |
1 2 4 3 |
1 4 2 3 | 2 1 4 3 |
1 4 3 2 | 4 1 2 3 | 2 1 3 4 | 2 4 1 3 |
1 3 4 2 | 4 1 3 2 | 2 4 3 1 | 4 2 1 3 |
1 3 2 4 | 3 1 4 2 | 4 3 1 2 | 2 3 4 1 | 4 2 3 1 |
3 1 2 4 | 3 4 1 2 | 2 3 1 4 | 3 2 4 1 | 4 3 2 1 |
3 2 1 4 | 3 4 2 1 |


real    0m0.964s
user    0m0.000s
sys     0m0.002s
```

For n=9

```
7 4 5 8 6 | 9 1 2 3 7 4 5 6 8 | 1 2 7 3 8 4 5 6 9 | 1 2 7 8 3 4 5
2 3 8 4 5 9 6 | 1 7 2 3 4 8 9 5 6 | 1 7 2 3 9 4 8 5 6 | 1 7 2 9 3 4
8 1 2 3 4 9 5 6 7 | 1 8 2 3 9 4 5 6 7 | 1 2 8 9 3 4 5 6 7 | 1 9 2 8
6 | 1 9 2 3 8 4 5 7 6 | 9 1 2 3 4 8 5 7 6 | 1 8 2 3 4 7 5 6 9 | 8 1
8 5 6 | 1 2 8 3 7 4 5 6 9 | 1 8 2 3 7 4 5 9 6 | 1 2 8 3 7 4 9 5 6 |
3 4 5 9 6 | 1 2 7 8 3 4 9 5 6 | 1 2 7 3 8 9 4 5 6 | 1 2 7 9 3 8 4 5
2 3 9 8 4 5 6 | 1 7 2 9 3 4 8 5 6 | 1 7 9 2 3 4 5 8 6 | 1 9 7 2 3 4
8 1 2 3 9 4 5 6 7 | 1 8 2 9 3 4 5 6 7 | 1 9 8 2 3 4 5 6 7 | 9 1 2 8
9 | 8 1 2 3 4 7 9 5 6 | 1 8 2 3 4 9 7 5 6 | 1 2 8 3 9 4 7 5 6 | 1 2
4 5 6 | 1 2 3 8 9 7 4 5 6 | 1 2 9 3 8 7 4 5 6 | 1 9 2 3 7 8 4 5 6 |
3 8 4 5 6 | 1 9 2 7 3 4 8 5 6 | 9 1 2 7 3 4 5 8 6 | 1 7 2 8 3 4 5 6
7 2 3 4 5 6 8 | 7 1 2 3 8 4 5 6 9 | 7 1 2 8 3 4 5 9 6 | 7 1 2 3 8 4
8 1 2 9 3 4 5 6 7 | 1 8 9 2 3 4 5 6 7 | 9 1 8 2 3 4 5 6 7 | 8 1 2 3
6 | 1 9 2 8 3 4 7 5 6 | 9 1 2 3 8 4 7 5 6 | 8 1 2 3 7 4 5 6 9 | 8 1
5 6 9 | 8 1 2 7 3 4 5 9 6 | 1 8 2 7 3 4 9 5 6 | 1 2 8 7 3 9 4 5 6 |
3 4 9 5 6 | 1 7 2 8 3 9 4 5 6 | 1 7 2 9 8 3 4 5 6 | 1 7 9 2 3 8 4 5
2 9 3 8 4 5 6 | 7 1 9 2 3 4 8 5 6 | 7 9 1 2 3 4 5 8 6 | 9 7 1 2 3 4
8 1 9 2 3 4 5 6 7 | 9 8 1 2 3 4 5 6 7 | 8 1 2 9 3 4 5 7 6 | 1 8 9 2
6 | 1 8 2 3 9 7 4 5 6 | 1 2 8 9 3 7 4 5 6 | 1 9 2 8 3 7 4 5 6 | 9 1
4 5 6 | 9 1 2 7 3 8 4 5 6 | 1 8 7 2 3 4 5 6 9 | 8 1 7 2 3 4 5 9 6 |
3 4 5 6 9 | 7 8 1 2 3 4 5 9 6 | 7 1 8 2 3 4 9 5 6 | 7 1 2 8 3 9 4 5
8 9 1 2 3 4 5 6 7 | 8 1 9 2 3 4 5 7 6 | 9 8 1 2 3 4 5 7 6 | 8 1 2 9
6 | 8 1 2 7 3 9 4 5 6 | 1 8 2 7 9 3 4 5 6 | 1 2 8 9 7 3 4 5 6 | 1 9
4 5 6 | 1 9 7 2 8 3 4 5 6 | 9 1 7 2 3 8 4 5 6 | 7 8 1 2 3 4 5 6 9 |
3 4 8 5 6 |
8 9 1 2 3 4 5 7 6 | 8 1 9 2 3 4 7 5 6 | 9 8 1 2 3 4 7 5 6 | 8 1 2 9
6 | 8 1 7 2 3 9 4 5 6 | 1 8 7 2 9 3 4 5 6 | 1 7 8 9 2 3 4 5 6 | 1 9
4 5 6 | 7 9 1 2 8 3 4 5 6 | 9 7 1 2 3 8 4 5 6 |
8 9 1 2 3 4 7 5 6 | 8 1 9 2 3 7 4 5 6 | 9 8 1 2 3 7 4 5 6 | 8 1 2 9
6 | 8 7 1 2 3 9 4 5 6 | 7 8 1 2 9 3 4 5 6 | 7 1 8 9 2 3 4 5 6 | 7 9
8 9 1 2 3 7 4 5 6 | 8 1 9 2 7 3 4 5 6 | 9 8 1 2 7 3 4 5 6 | 8 1 7 9
6 |
8 9 1 2 7 3 4 5 6 | 8 1 9 7 2 3 4 5 6 | 9 8 1 7 2 3 4 5 6 | 8 7 1 9
8 9 1 7 2 3 4 5 6 | 8 7 9 1 2 3 4 5 6 | 9 8 7 1 2 3 4 5 6 |
8 9 7 1 2 3 4 5 6 |


real    0m22.753s
user    0m16.800s
sys     0m0.272s
```

Profile Report:

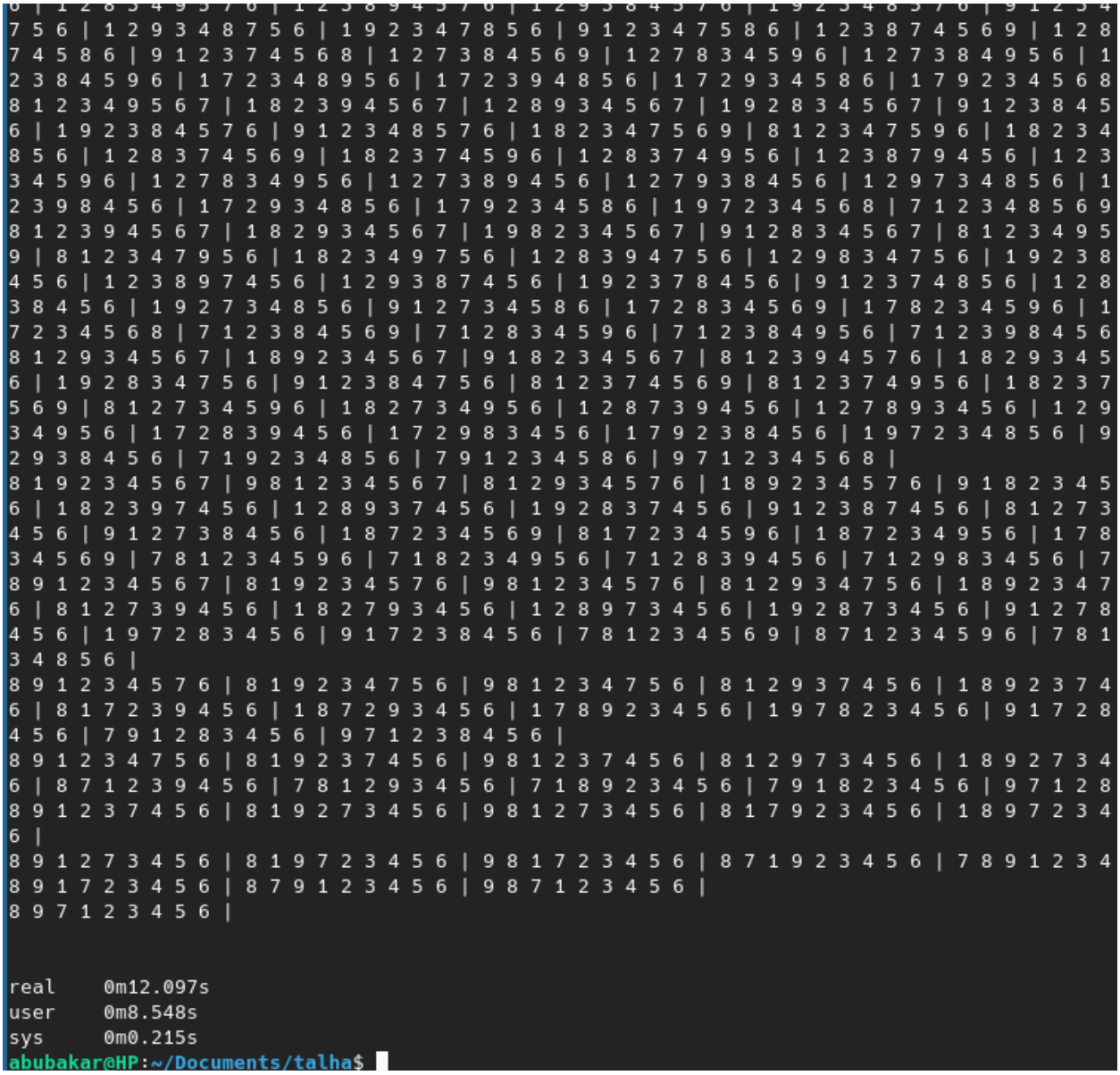


profile_report.txt gmon.out

home > abubakar > Documents > talha > profile_report.txt

```
Flat profile:

Each sample counts as 0.01 seconds.
 no time accumulated

  %   cumulative   self              self     total
 time   seconds   seconds    calls  Ts/call  Ts/call  name
  0.00      0.00     0.00      328     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::base() const
  0.00      0.00     0.00      298     0.00     0.00  __gnu_cxx::__normal_iterator<int const*, std::vector<int, std::allocator<int> > >::__normal_iterator(int const* const&)
  0.00      0.00     0.00      298     0.00     0.00  __gnu_cxx::__normal_iterator<int const*, std::vector<int, std::allocator<int> > >::base() const
  0.00      0.00     0.00      298     0.00     0.00  int const* std::__niter_base<int const*, std::vector<int, std::allocator<int> > >(__gnu_cxx::__normal_iterator<int const*,
 std::vector<int, std::allocator<int> > >)
  0.00      0.00     0.00      202     0.00     0.00  bool __gnu_cxx::__ops::_Iter_less_iter::operator()<int const*, int const*>(int const*, int const*) const
  0.00      0.00     0.00      150     0.00     0.00  std::vector<int, std::allocator<int> >::begin() const
  0.00      0.00     0.00      148     0.00     0.00  std::vector<int, std::allocator<int> >::end() const
  0.00      0.00     0.00      121     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::__normal_iterator(int* const&)
  0.00      0.00     0.00      117     0.00     0.00  bool std::__lc_rai<std::random_access_iterator_tag, std::random_access_iterator_tag>::__cnd2<int const*>(int const*, int const*)
  0.00      0.00     0.00      116     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::operator*() const
  0.00      0.00     0.00       97     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::_M_get_Tp_allocator()
  0.00      0.00     0.00       95     0.00     0.00  std::vector<int, std::allocator<int> >::size() const
  0.00      0.00     0.00       86     0.00     0.00  int* std::__niter_base<int*>(int*)
  0.00      0.00     0.00       82     0.00     0.00  std::allocator<int>::~allocator()
  0.00      0.00     0.00       82     0.00     0.00  std::__new_allocator<int>::~__new_allocator()
  0.00      0.00     0.00       74     0.00     0.00  bool __gnu_cxx::operator!=<int*, std::vector<int, std::allocator<int> > >(__gnu_cxx::__normal_iterator<int*, std::vector<int,
 std::allocator<int> > > const&, __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > > const&)
  0.00      0.00     0.00       67     0.00     0.00  std::vector<int, std::allocator<int> >::begin()
  0.00      0.00     0.00       67     0.00     0.00  std::remove_reference<int&>::type&& std::move<int&>(int&)
  0.00      0.00     0.00       66     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::operator++()
  0.00      0.00     0.00       66     0.00     0.00  __gnu_cxx::__ops::__iter_less_iter()
  0.00      0.00     0.00       65     0.00     0.00  std::allocator<int>::allocator(std::allocator<int> const&)
  0.00      0.00     0.00       65     0.00     0.00  std::__new_allocator<int>::__new_allocator(std::__new_allocator<int> const&)
  0.00      0.00     0.00       64     0.00     0.00  std::__new_allocator<int>::_M_max_size() const
  0.00      0.00     0.00       61     0.00     0.00  __gnu_cxx::__aligned_membuf<std::pair<std::vector<int, std::allocator<int> > const, int> >::_M_ptr() const
  0.00      0.00     0.00       61     0.00     0.00  __gnu_cxx::__aligned_membuf<std::pair<std::vector<int, std::allocator<int> > const, int> >::_M_addr() const
  0.00      0.00     0.00       61     0.00     0.00  std::_Select1st<std::pair<std::vector<int, std::allocator<int> > const, int> >::operator()(std::pair<std::vector<int,
 std::allocator<int> > const, int> const&) const
  0.00      0.00     0.00       61     0.00     0.00  std::_Rb_tree_node<std::pair<std::vector<int, std::allocator<int> > const, int> >::_M_valptr() const
```

OpenMP Performance(n=9):



Profile Report:

profile_report.txt

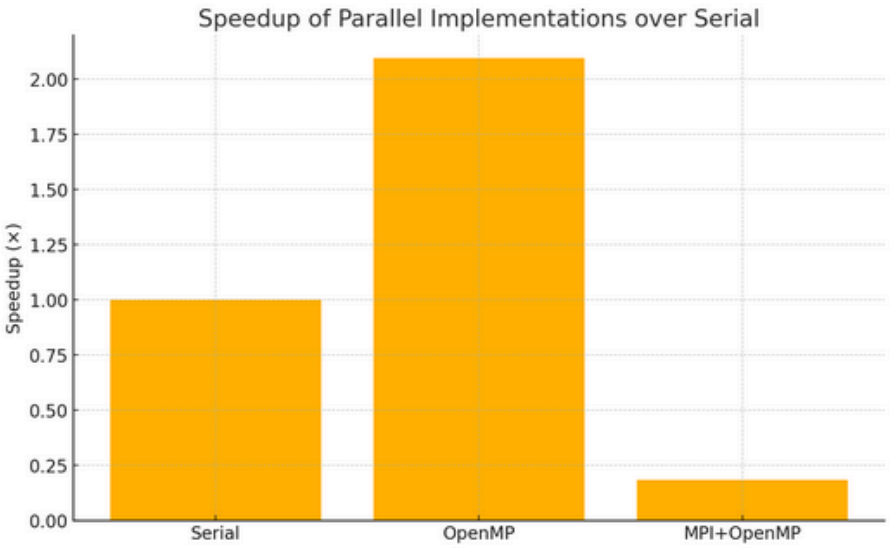
abubakar > Documents > talha > profile_report.txt

```
Flat profile:

Each sample counts as 0.01 seconds.
 no time accumulated

  %   cumulative   self              self     total
 time   seconds   seconds    calls  Ts/call  Ts/call  name
  0.00      0.00     0.00     2274     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::base() const
  0.00      0.00     0.00      861     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::operator*() const
  0.00      0.00     0.00      789     0.00     0.00  bool __gnu_cxx::operator!=<int*, std::vector<int, std::allocator<int> > >(__gnu_cxx::__normal_iterator<int*, std::vector<int,
 std::allocator<int> > > const&, __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > > const&)
  0.00      0.00     0.00      707     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::__normal_iterator(int* const&)
  0.00      0.00     0.00      652     0.00     0.00  __gnu_cxx::__normal_iterator<int*, std::vector<int, std::allocator<int> > >::operator++()
  0.00      0.00     0.00      475     0.00     0.00  int* std::__niter_base<int*>(int*)
  0.00      0.00     0.00      434     0.00     0.00  std::vector<int, std::allocator<int> >::size() const
  0.00      0.00     0.00      390     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::_M_get_Tp_allocator()
  0.00      0.00     0.00      372     0.00     0.00  std::vector<int, std::allocator<int> >::begin()
  0.00      0.00     0.00      345     0.00     0.00  int const& std::forward<int const&>(std::remove_reference<int const&>::type&)
  0.00      0.00     0.00      339     0.00     0.00  std::vector<int, std::allocator<int> >::end()
  0.00      0.00     0.00      317     0.00     0.00  operator new(unsigned long, void*)
  0.00      0.00     0.00      281     0.00     0.00  std::__new_allocator<int>::_M_max_size() const
  0.00      0.00     0.00      274     0.00     0.00  std::vector<std::vector<int, std::allocator<int> >, std::allocator<std::vector<int, std::allocator<int> > > >::operator[]
 (unsigned long)
  0.00      0.00     0.00      261     0.00     0.00  std::vector<int, std::allocator<int> >* std::__addressof<std::vector<int, std::allocator<int> > >(std::vector<int,
 std::allocator<int> >&)
  0.00      0.00     0.00      254     0.00     0.00  std::allocator<int>::~allocator()
  0.00      0.00     0.00      252     0.00     0.00  std::__new_allocator<int>::~__new_allocator()
  0.00      0.00     0.00      247     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::_M_deallocate(int*, unsigned long)
  0.00      0.00     0.00      233     0.00     0.00  std::remove_reference<int&>::type&& std::move<int&>(int&)
  0.00      0.00     0.00      193     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::_M_get_Tp_allocator() const
  0.00      0.00     0.00      177     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::_Vector_impl::~_Vector_impl()
  0.00      0.00     0.00      175     0.00     0.00  void std::_Destroy_aux<true>::__destroy<int*>(int*, int*)
  0.00      0.00     0.00      175     0.00     0.00  std::_Vector_base<int, std::allocator<int> >::~_Vector_base()
  0.00      0.00     0.00      175     0.00     0.00  std::vector<int, std::allocator<int> >::operator[](unsigned long)
  0.00      0.00     0.00      172     0.00     0.00  std::vector<int, std::allocator<int> >::~vector()
  0.00      0.00     0.00      172     0.00     0.00  void std::_Destroy<int*>(int*, int*)
  0.00      0.00     0.00      168     0.00     0.00  std::__new_allocator<int>::__new_allocator(std::__new_allocator<int> const&)
  0.00      0.00     0.00      167     0.00     0.00  std::allocator<int>::allocator(std::allocator<int> const&)
  0.00      0.00     0.00      167     0.00     0.00  void std::_Destroy<int*, int>(int*, int*, std::allocator<int>&)
```

OpenMP and MPI Performance:

```
user@user-Precision-7510:~$ mpic++ -fopenmp a.cpp -o hello
a.cpp: In function ‘void level_order_tree(const Permutation&, const IST&)’:
a.cpp:50:22: warning: structured bindings only available with ‘-std=c++17’ or ‘-std=gnu++17’
   50 |     for (const auto &[child, parent] : tree) {
      |                      ^
a.cpp:55:16: warning: structured bindings only available with ‘-std=c++17’ or ‘-std=gnu++17’
   55 |     for (auto &[parent, children] : children_map) {
      |                ^
a.cpp: In function ‘std::vector<int> serializeIST(const IST&, int)’:
a.cpp:146:22: warning: structured bindings only available with ‘-std=c++17’ or ‘-std=gnu++17’
  146 |     for (const auto& [child, parent] : ist) {
      |                      ^
user@user-Precision-7510:~$ scp hello user@192.168.18.129:~/
hello
user@user-Precision-7510:~$ mpirun -np 4 --hostfile hosts --prefix /usr/local ./hello
Degree: 9
Degree: 9
Degree: 9
Degree: 9

Total execution time: 90.8495 seconds.
```

SpeedUp Graph:



Performance Table

Implementation	Execution Time (s)	Speedup (×)
Serial	16.34	1.00
OpenMP	7.80	2.10
MPI + OpenMP	88.823	0.18