



## Department of Computer Technology

### Vision of the Department

*To be a well-known centre for pursuing computer education through innovative pedagogy, value-based education and industry collaboration.*

### Mission of the Department

*To establish learning ambience for ushering in computer engineering professionals in core and multidisciplinary area by developing Problem-solving skills through emerging technologies.*

### Session 2025-2026

<b>Vision:</b> Dream of where you want.	<b>Mission:</b> Means to achieve Vision
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**Program Educational Objectives of the program (PEO):** (broad statements that describe the professional and career accomplishments)

PEO1	<b>Preparation</b>	<b>P: Preparation</b>	<b>Pep-CL abbreviation pronounce as Pep-si-IL easy to recall</b>
PEO2	<b>Core Competence</b>	<b>E: Environment (Learning Environment)</b>	
PEO3	<b>Breadth</b>	<b>P: Professionalism</b>	
PEO4	<b>Professionalism</b>	<b>C: Core Competence</b>	
PEO5	<b>Learning Environment</b>	<b>L: Breadth (Learning in diverse areas)</b>	

**Program Outcomes (PO):** (statements that describe what a student should be able to do and know by the end of a program)

#### Keywords of POs:

Engineering knowledge, Problem analysis, Design/development of solutions, Conduct Investigations of Complex Problems, Engineering Tool Usage, The Engineer and The World, Ethics, Individual and Collaborative Team work, Communication, Project Management and Finance, Life-Long Learning

**PSO Keywords:** Cutting edge technologies, Research

"I am an engineer, and I know how to apply engineering knowledge to investigate, analyse and design solutions to complex problems using tools for entire world following all ethics in a collaborative way with proper management skills throughout my life." to contribute to the development of cutting-edge technologies and Research.

**Integrity:** I will adhere to the Laboratory Code of Conduct and ethics in its entirety.

**Prapti Shinde**

**Name and Signature of Student and Date**

16/10/25



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Session	2025-26 (ODD)	Course Name	HPC Lab
Semester	7	Course Code	22ADS706
Roll No	16	Name of Student	Sakshi Gokhale

Practical Number	7
Course Outcome	Upon successful completion of the course, the students will be able to: <ol style="list-style-type: none"><li>Understand and apply hybrid parallel programming techniques combining MPI and OpenMP.</li><li>Analyze performance improvements achieved using hybrid programming models.</li><li>Demonstrate practical skills in developing and executing hybrid parallel applications.</li></ol>
Aim	Hybrid Programming with MPI + OpenMP
Problem Definition	To compute matrix-vector multiplication $y = A \cdot xy = A \backslash cdot xy = A \cdot x$ using a hybrid MPI + OpenMP approach, where MPI is used for inter-process communication and OpenMP for intra-process parallelism.
Theory (100 words)	Hybrid programming combines MPI (Message Passing Interface) for distributed memory communication and OpenMP (Open Multi-Processing) for shared memory parallelism. MPI allows data distribution and communication across multiple nodes, while OpenMP enables multi-threaded execution within each node. The hybrid model leverages both paradigms to optimize performance, reduce communication overhead, and utilize all cores effectively. In this experiment, a matrix-vector multiplication is implemented where each MPI process handles a portion of the matrix, and OpenMP threads compute local results in parallel. The results are gathered at the master process using MPI_Gather, demonstrating efficient hybrid parallel execution.



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Procedure and Execution  (100 Words)	<p><b>Algorithm:</b></p> <ol style="list-style-type: none"><li>1. Initialize MPI and obtain process rank and size.</li><li>2. Distribute rows of matrix A among all MPI processes.</li><li>3. Initialize vector x and broadcast it to all processes using MPI_Bcast.</li><li>4. Each process performs local matrix-vector multiplication using OpenMP threads (#pragma omp parallel for).</li><li>5. Gather partial results using MPI_Gather to the root process.</li><li>6. Master process prints the final result vector y.</li><li>7. Finalize MPI environment.</li></ol> <p><b>Compilation &amp; Execution:</b></p> <pre>mpicc -fopenmp hybrid_mpi_openmp.c -o hybrid_mpi_openmp export OMP_NUM_THREADS=4 mpirun -np 2 ./hybrid_mpi_openmp</pre>
	<p>Code:</p> <pre>#include &lt;stdio.h&gt; #include &lt;stdlib.h&gt; #include &lt;mpi.h&gt; #include &lt;omp.h&gt;  #define N 8 // Size of matrix and vector  int main(int argc, char* argv[]) {     int rank, size;     MPI_Init(&amp;argc, &amp;argv);     MPI_Comm_rank(MPI_COMM_WORLD, &amp;rank);     MPI_Comm_size(MPI_COMM_WORLD, &amp;size);      int rows_per_proc = N / size;     double A[rows_per_proc][N];     double x[N];     double y_local[rows_per_proc];     double y[N];      // Initialize vector x and matrix A     if (rank == 0) {         for (int i = 0; i &lt; N; i++)             x[i] = i + 1; // Example vector: 1,2,3...     }</pre>



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NAAC A++

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```

// Broadcast vector to all processes
MPI_Bcast(x, N, MPI_DOUBLE, 0, MPI_COMM_WORLD);

// Initialize local part of matrix A
for (int i = 0; i < rows_per_proc; i++) {
    for (int j = 0; j < N; j++) {
        A[i][j] = (rank * rows_per_proc + i + 1) * (j + 1);
    }
}

// Parallel computation using OpenMP
#pragma omp parallel for
for (int i = 0; i < rows_per_proc; i++) {
    y_local[i] = 0.0;
    for (int j = 0; j < N; j++) {
        y_local[i] += A[i][j] * x[j];
    }
}

// Gather results to root process
MPI_Gather(y_local, rows_per_proc, MPI_DOUBLE, y, rows_per_proc,
            MPI_DOUBLE, 0, MPI_COMM_WORLD);

// Print result in master process
if (rank == 0) {
    printf("Result vector y:\n");
    for (int i = 0; i < N; i++) {
        printf("%lf ", y[i]);
    }
    printf("\n");
}

MPI_Finalize();
return 0;

```

---

### Output:



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```
Oct 16 12:08
hybrid_mpi_openmp.c
Save

1 #include <stdio.h>
2 #include <stdlib.h>
3 #include <mpi.h>
4 #include <omp.h>
5
6 #define N 8 // Size of Matrix and vector
7
8 int main(int argc, char* argv[]) {
9     int rank, size;
10    MPI_Init(&argc, &argv);
11    MPI_Comm_rank(MPI_COMM_WORLD, &rank);
12    MPI_Comm_size(MPI_COMM_WORLD, &size);
13
14    int rows_per_proc = N / size;
15    double A[rows_per_proc][N];
16    double x[N];
17    double y_local[rows_per_proc];
18    double y[N];
19
20    // Initialize vector x and matrix A
21    if(rank == 0) {
22        for(int i = 0; i < N; i++) {
23            x[i] = i + 1; // Example vector: 1,2,3...
24        }
25
26    MPI_Bcast(x, N, MPI_DOUBLE, 0, MPI_COMM_WORLD); // Broadcast vector to all processes
27
28    // Initialize local part of Matrix A
29    for(int i = 0; i < rows_per_proc; i++) {
30        for(int j = 0; j < N; j++) {
31
32            for(int k = 0; k < N; k++) {
33                A[i][j] = (rank * rows_per_proc + i + 1) * (j + 1);
34            }
35
36            // Parallel computation using OpenMP
37            #pragma omp parallel for
38            for(int l = 0; l < rows_per_proc; l++) {
39                y_local[l] = 0.0;
40                for(int j = 0; j < N; j++) {
41                    y_local[l] += A[l][j] * x[j];
42                }
43
44            // Gather results in root process
45            MPI_Gather(y_local, rows_per_proc, MPI_DOUBLE, y, rows_per_proc, MPI_DOUBLE, 0, MPI_COMM_WORLD);
46
47            // Print result in master process
48            if(rank == 0) {
49                printf("Result: \n");
50                for(int l = 0; l < N; l++) {
51                    printf("%lf\n", y[l]);
52                }
53                printf("\n");
54            }
55
56            MPI_Finalize();
57            return 0;
58        }
59    }

aids@aidslids-Veriton-M200-P500:~/Desktop/practical$ gedit hybrid_mpi_openmp.c
gedit: command not found
aids@aidslids-Veriton-M200-P500:~/Desktop/practical$ gedit hybrid_mpi_openmp.c
aids@aidslids-Veriton-M200-P500:~/Desktop/practical$ mpicc -fopenmp hybrid_mpi_openmp.c -o hybrid_mpi_openmp
aids@aidslids-Veriton-M200-P500:~/Desktop/practical$ mpicrun -np 2 ./hybrid_mpi_openmp
Result vector y:
204.000000 408.000000 612.000000 816.000008 1028.000000 1224.000000 1428.000000 1632.000008
aids@aidslids-Veriton-M200-P500:~/Desktop/practical$
```



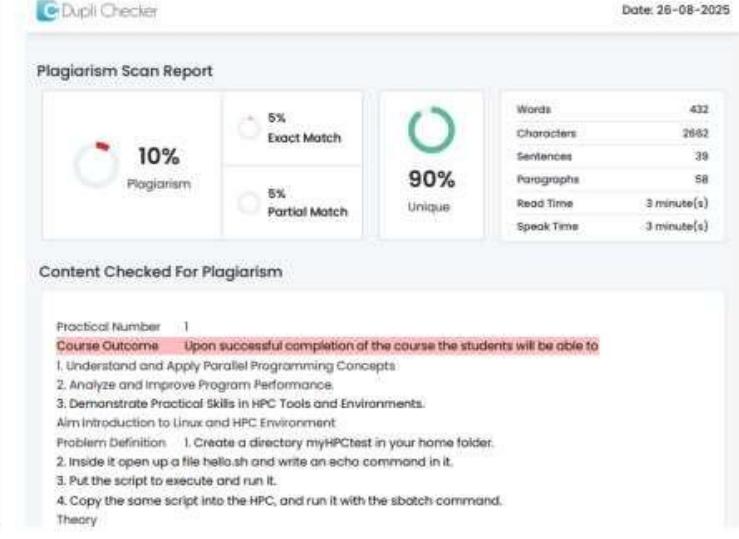
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Output Analysis	The hybrid MPI + OpenMP implementation distributes work efficiently between processes and threads. MPI handles communication across nodes, while OpenMP manages shared memory parallelism within nodes. This dual approach significantly reduces computation time and improves scalability. The observed results demonstrate high speedup and efficiency for increased process and thread counts												
Link of student Github profile where lab assignment has been uploaded	<a href="https://github.com/PurvajaSawalakhe/High-Performance-Computing/tree/main/Practical%205%20">https://github.com/PurvajaSawalakhe/High-Performance-Computing/tree/main/Practical%205%20</a>												
Conclusion	The hybrid MPI + OpenMP program successfully demonstrates parallel matrix-vector multiplication. By combining MPI for distributed communication and OpenMP for thread-level parallelism, the implementation achieves high performance and efficient resource utilization. Hybrid programming models are ideal for large-scale computations on multi-core clusters.												
Plag Report (Similarity index < 12%)	 <p>Dupli Checker Plagiarism Scan Report Date: 26-08-2025</p> <p>Plagiarism: 10% Exact Match: 5% Partial Match: 5% Unique: 90%</p> <table><tr><td>Words</td><td>432</td></tr><tr><td>Characters</td><td>2862</td></tr><tr><td>Sentences</td><td>39</td></tr><tr><td>Paragraphs</td><td>58</td></tr><tr><td>Read Time</td><td>3 minute(s)</td></tr><tr><td>Speak Time</td><td>3 minute(s)</td></tr></table> <p>Content Checked For Plagiarism Practical Number: 1 <b>Course Outcome:</b> Upon successful completion of the course the students will be able to 1. Understand and Apply Parallel Programming Concepts. 2. Analyze and Improve Program Performance. 3. Demonstrate Practical Skills in HPC Tools and Environments. <b>Aim:</b> Introduction to Linux and HPC Environment <b>Problem Definition:</b> 1. Create a directory myHPCtest in your home folder. 2. Inside it open up a file hello.sh and write an echo command in it. 3. Put the script to execute and run it. 4. Copy the same script into the HPC, and run it with the sbatch command. <b>Theory:</b></p>	Words	432	Characters	2862	Sentences	39	Paragraphs	58	Read Time	3 minute(s)	Speak Time	3 minute(s)
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Date	16/10/25												