

High Performance Computing

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Batch-14

Week-4

LAB Assignment-4 (04/02/2026)

Task 1: OpenMP Parallel Loops (From Serial to Parallel)

Objective: Confirm OpenMP-ready system.

Steps:

- lscpu
- nproc
- gcc --version

Expected Observation:

Multiple CPU cores available

GCC installed with OpenMP support

Screenshots:

```
shyam@vassdevkxipeta:~$ lscpu
To run a command as administrator (user "root"), use "sudo <command>".
See "man sudo_root" for details.

Architecture:          x86_64
CPU op-mode(s):        32-bit, 64-bit
Address sizes:         39 bits physical, 48 bits virtual
Byte Order:            Little Endian
CPU(s):                16
On-line CPU(s) list:  0-15
Vendor ID:             GenuineIntel
Model name:            10th Gen Intel(R) Core(TM) i5-1240P
CPU family:            6
Model:                 15H
Thread(s) per core:   2
Core(s) per socket:   8
Socket(s):            1
Stepping:              3
BogomIPS:              4223.99
Flags:                 fpu vme de pse tsc msr pae mca cx8 apic sep mtrr pge mca cmov pat pae36 clflush mmx fxsr ure s
ue2 ue3 st syscall ns pdpe1gb rdtspc lm constant_tsc rep_good mopl topology tsc_reliable nopl
apic tsc cpuid tsc_known_freq pni pclmulqdq vmx vmm3d fm cxi6 pied esel_1 tsx4_2 x2apic movbe t
pqrst tsc_deadline_timer aes ssse3 avx f16c rdrand hypervisor tshf_lm abm 3dnopprefetch ssbd i
bsi ibpb stibp ibrs_enhanced tpr_shadow ept vpid ept_ad fsgsbase tsc_adjust bndlf avx2 seep hml
2 rmrs invpcid rdseed adx ssse3 clflushopt clmb sha_ni ssse3p ssse3p xgetbv1 ssaves avx_vnni
vnni uskip waitpk gfmr vass vpcimulqos rdpid movdir64b fma4 md_clear serialize flush_l
id arch_capabilities

Virtualization features:
Virtualization:        VT-x
Hyperervisor vendor:   Microsoft
Virtualization type:   full
Caches (sum of all):
L1d:                  384 KIB (8 instances)
L1i:                  256 KIB (8 instances)
L2:                   18 MIB (8 instances)
L3:                   12 MIB (1 instance)

NUMA:
    NUMA node(s):       1
    NUMA node0 CPU(s):  0-15
Vulnerabilities:
    Gather data sampling: Not affected
    Icb multibit:        Not affected
    L1tf:                 Not affected
    Nds:                  Not affected
    Meltdown:            Not affected
    Msr stale data:      Not affected
    Reg file data sampling: Mitigation; Clear Register File
    Retbleed:             Mitigation; Enhanced IBS
    Spec rstack overflow: Not affected
    Spec store bypass:   Mitigation; Speculative Store Bypass disabled via prctl
    Spectre v1:           Mitigation; usercopy/mmap barriers and __user pointer sanitization
    Spectre v2:           Mitigation; Enhanced / Automatic IBRS; IBRS conditional; RSB Filling; PURRS=IBRS SW sequence;
    Smbds:                BHI BHI_DTS_S
    Tax async abort:      Not affected
shyam@vassdevkxipeta:~$
```

```
shyam@vassdevkxipeta:~$ + ~
        id.arch_capabilities

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Virtualization:        VT-x
Hypervisor vendor:   Microsoft
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    Nds:                  Not affected
    Meltdown:            Not affected
    Msr stale data:      Not affected
    Reg file data sampling: Mitigation; Clear Register File
    Retbleed:             Mitigation; Enhanced IBS
    Spec rstack overflow: Not affected
    Spec store bypass:   Mitigation; Speculative Store Bypass disabled via prctl
    Spectre v1:           Mitigation; usercopy/mmap barriers and __user pointer sanitization
    Spectre v2:           Mitigation; Enhanced / Automatic IBRS; IBRS conditional; RSB Filling; PURRS=IBRS SW sequence;
    Smbds:                BHI BHI_DTS_S
    Tax async abort:      Not affected
shyam@vassdevkxipeta:~$
```

```
shyam@vassdevkxipeta:~$ + ~
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Vulnerabilities:
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    L1tf:                 Not affected
    Nds:                  Not affected
    Meltdown:            Not affected
    Msr stale data:      Not affected
    Reg file data sampling: Mitigation; Clear Register File
    Retbleed:             Mitigation; Enhanced IBS
    Spec rstack overflow: Not affected
    Spec store bypass:   Mitigation; Speculative Store Bypass disabled via prctl
    Spectre v1:           Mitigation; usercopy/mmap barriers and __user pointer sanitization
    Spectre v2:           Mitigation; Enhanced / Automatic IBRS; IBRS conditional; RSB Filling; PURRS=IBRS SW sequence;
    Smbds:                BHI BHI_DTS_S
    Tax async abort:      Not affected
shyam@vassdevkxipeta:~$ nproc
26
shyam@vassdevkxipeta:~$
```

```

shylar@shylar-laptop:~$ x - + ~
Spectre v1 Mitigation: usercopy/mmap barriers and __user pointer sanitization
Spectre v2 Mitigation: Enhanced / Automatic IBRS; IBPB conditional; RSB filling; RRSB-eIBRS SW sequence;
SMBW: Not affected
Ttx async abort: Not affected
shylar@shylar-laptop:~$ lproc
16
shylar@shylar-laptop:~$ gcc --version
Command 'gcc' not found, but can be installed with:
sudo apt install gcc
[sudo] password for shylar:
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  cpp cpp-13 cpp-13-base g++-13 g++-13-base gcc-13 gcc-13-base gcc-13-x86-64-linux-gnu gcc-x86-64-linux-gnu libasan3 libasan4 libatomic1
  libc-dev-him libc-dev-tools libc6-dev libcrypt1-dev libde265-0 libgcc-13-dev libgd1 libgnupg libheif-plugin-aomenc
  libheif-plugin-libde265 libheif1 libhevcn8 libis123 liblml liblsan8 libmpc3 libquadmath0 libtsan2 libubsan1 libxpm4 linux-libc-dev manpages-dev
  rpcsvc-proto
Suggested packages:
  eglibc-doc gcc-13-locales gpp-13-gcc gcc-multilib make automake libtool flex bison gdb gcc-dec gcc-13-multilib gcc-13-dmc gdm-x86-64-linux-gnu
  glib2.68 libhd-tools libheif-plugin-x265 libheif-plugin-ffmpgdec libheif-plugin-jpegdec libheif-plugin-aomenc
  libheif-plugin-jpgenc libheif-plugin-rav3e libheif-plugin-svtenc
The following NEW packages will be installed:
  cpp cpp-13 cpp-13-x86-64-linux-gnu cpp-13-x86-64-linux-gnu g++-13 g++-13-base gcc-13-x86-64-linux-gnu gcc-x86-64-linux-gnu libasan3 libasan4 libatomic1
  libc-dev-him libc-dev-tools libc6c1-0 libcrypt-dev libde265-0 libgcc-13-dev libgd1 libgnupg libheif-plugin-aomenc
  libheif-plugin-libde265 libheif1 libhevcn8 libis123 liblml liblsan8 libmpc3 libquadmath0 libtsan2 libubsan1 libxpm4 linux-libc-dev manpages-dev
  rpcsvc-proto
0 upgraded, 37 newly installed, 0 to remove and 0 not upgraded.
Need to get 55.0 MB of archives.
After this operation, 181 MB of additional disk space will be used.
Do you want to continue? [Y/n] Y
Get:1 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 gcc-13-base amd64 13.3.0-6ubuntu2-24.04 [31.5 kB]
Get:2 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libis123 amd64 0.26-3build1.1 [689 kB]
Get:3 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libmpc3 amd64 1.3.1-1build1.1 [94.6 kB]
Get:4 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 cpp-13-x86-64-linux-gnu amd64 13.3.0-6ubuntu2-24.04 [10.7 kB]
Get:5 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 cpp-13 amd64 13.3.0-6ubuntu2-24.04 [1030 kB]
Get:6 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libgcc-13-x86-64-linux-gnu amd64 13.3.0-6ubuntu2-24.04 [5326 kB]
Get:7 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libgcc1-0 amd64 13.2.0-7ubuntu1 [22.4 kB]
Get:8 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 liblml-0 amd64 14.2.0-4ubuntu2-24.04 [48.8 kB]
Get:9 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libgnupg1 amd64 14.2.0-4ubuntu2-24.04 [148 kB]
Get:10 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 liblml1 amd64 14.2.0-4ubuntu2-24.04 [29.7 kB]
Get:11 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libatomic1 amd64 14.2.0-4ubuntu2-24.04 [18.5 kB]
Get:12 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libasan3 amd64 14.2.0-4ubuntu2-24.04 [3831 kB]
Get:13 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 liblsan8 amd64 14.2.0-4ubuntu2-24.04 [1322 kB]
Get:14 http://archive.ubuntu.com/ubuntu focal-updates/main amd64 libquadmath0 amd64 14.2.0-4ubuntu2-24.04 [2772 kB]

```

Task 2: Serial Baseline – Loop Computation

Objective: Establish serial execution time.

File: sum_serial.c

```

#include <stdio.h>

#include <time.h>

#define N 100000000

int main() {

    double sum = 0.0;

    clock_t start = clock();

    for (long i = 0; i < N; i++) {

        sum += i * 0.5;

    }

    clock_t end = clock();

    double time_spent = (double)(end - start) /

```

CLOCKS_PER_SEC;

```
printf("Serial Sum: %f\n", sum);
printf("Execution Time: %f seconds\n", time_spent);

return 0;
```

Compile & Run:

```
&gt; gcc sum_serial.c -o sum_serial
```

```
&gt; ./sum_serial
```

Submission: Screenshot showing execution time.

```
GNU nano 7.2                                     sum_serial.c *

#include <stdio.h>
#include <time.h>

#define N 100000000

int main() {
    double sum = 0.0;
    clock_t start = clock();

    for (long i = 0; i < N; i++) {
        sum += i * 0.5;
    }

    clock_t end = clock();

    double time_spent = (double)(end - start) / CLOCKS_PER_SEC;

    printf("Serial Sum: %f\n", sum);
    printf("Execution Time: %f seconds\n", time_spent);

    return 0;
}
```

```
Get:22 http://archive.ubuntu.com/ubuntu noble/main amd64 gcc amd64 4:13.2.0-7ubuntu1 [5018 kB]
Get:23 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libgcc1 amd64 3.8.2~ubuntu0.1 [1941 kB]
Ign:24 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libc-dev-bin amd64 2.39~ubuntu0.5
Ign:25 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libdhe225-amd64 amd64 1.17.6~ubuntu0.1
Get:26 http://archive.ubuntu.com/ubuntu noble/main amd64 libdhe225-0 amd64 1.8.15~1build3 [166 kB]
Ign:27 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libheif-plugin-libmjpeg265 amd64 1.17.6~ubuntu0.1
Ign:28 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libheif1 amd64 1.17.6~ubuntu0.1
Get:29 http://archive.ubuntu.com/ubuntu noble/main amd64 libpodofo amd64 1.13.5~17-build2 [36.9 kB]
Get:30 http://archive.ubuntu.com/ubuntu noble/main amd64 libpq3 amd64 2.3.3~ubuntu0.5 [138 kB]
Ign:31 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libdc1394-dev amd64 2.19~ubuntu0.5
Ign:32 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 linux-libc-dev amd64 5.6.0-71.71
Get:33 http://archive.ubuntu.com/ubuntu noble/main amd64 libcrypt-dev amd64 1:4.4.36-1build1 [112 kB]
Get:34 http://archive.ubuntu.com/ubuntu noble/main amd64 libcurl4-openssl-dev amd64 1.4.2~ubuntu0.7 [67.4 kB]
Ign:35 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libfcgi-dev amd64 2.39~ubuntu0.5
Ign:36 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 libheif-plugin-aomenc amd64 1.17.6~ubuntu0.1
Get:37 http://archive.ubuntu.com/ubuntu noble/main amd64 manpages-dev all 6.7-7 [2817 kB]
Err:24 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libc-dev-bin amd64 2.39~ubuntu0.5
  404 Not Found [IP: 185.125.199.83 80]
Err:25 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libheif-plugin-aomdec amd64 1.17.6~ubuntu0.1
  404 Not Found [IP: 185.125.199.83 80]
Err:27 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libheif-plugin-libdhe225 amd64 1.17.6~ubuntu0.1
  404 Not Found [IP: 185.125.199.83 80]
Err:28 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libheif1 amd64 1.17.6~ubuntu0.1
  404 Not Found [IP: 185.125.199.83 80]
Err:31 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libfcgi-dev-tools amd64 2.39~ubuntu0.5
  404 Not Found [IP: 185.125.199.83 80]
Err:32 http://security.ubuntu.com/ubuntu noble-updates/main amd64 linux-libc-dev amd64 5.6.0-71.71
  404 Not Found [IP: 185.125.199.83 80]
Err:35 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libfcgi-dev amd64 2.39~ubuntu0.5
  404 Not Found [IP: 185.125.199.83 80]
Err:36 http://security.ubuntu.com/ubuntu noble-updates/main amd64 libheif-plugin-aomenc amd64 1.17.6~ubuntu0.1
  404 Not Found [IP: 185.125.199.83 80]
Fetched:58.6 MB in 11s (4543 kB/s)
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/g/libc/libc-dev-bin_2.39~Ubuntu0.5_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/lib/libheif1/libheif1_1.17.6~ubuntu0.1_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/lib/libheif-plugin-aomdec_1.17.6~ubuntu0.1_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/l/libxml/libxml2_2.9.9~ubuntu0.5_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/m/libm/libm_1.17.6~ubuntu0.1_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Failed to fetch http://security.ubuntu.com/ubuntu/pool/main/L/liblzo/liblzo2_2.10~ubuntu0.5_amd64.deb 404 Not Found [IP: 185.125.199.83 80]
E: Unable to fetch some archives, maybe run apt-get update or try with --fix-missing?
shyali@shyaliuvkazipeta:~$ nano sum_serial.c
shyali@shyaliuvkazipeta:~$
```

```
shyleari@vassudevazipeta:~ % + ~
Get:16 http://security.ubuntu.com/ubuntu noble-security/restricted amd64 Components [212 kB]
Get:17 http://security.ubuntu.com/ubuntu noble-security/restricted amd64 c-n-f Metadata [536 kB]
Get:18 http://security.ubuntu.com/ubuntu noble-security/multiverse amd64 Packages [28.8 kB]
Get:19 http://security.ubuntu.com/ubuntu noble-security/multiverse Translation-en [6492 kB]
Get:20 http://security.ubuntu.com/ubuntu noble-security/multiverse amd64 Components [212 kB]
Get:21 http://security.ubuntu.com/ubuntu noble-security/multiverse amd64 c-n-f Metadata [396 kB]
Get:22 http://archive.ubuntu.com/ubuntu noble/universe Translation-en [5982 kB]
Get:23 http://archive.ubuntu.com/ubuntu noble/universe amd64 Components [3871 kB]
Get:24 http://archive.ubuntu.com/ubuntu noble/universe amd64 c-n-f Metadata [381 kB]
Get:25 http://archive.ubuntu.com/ubuntu noble/multiverse amd64 Packages [269 kB]
Get:26 http://archive.ubuntu.com/ubuntu noble/multiverse Translation-en [118 kB]
Get:27 http://archive.ubuntu.com/ubuntu noble/multiverse amd64 Components [35.6 kB]
Get:28 http://archive.ubuntu.com/ubuntu noble/multiverse amd64 c-n-f Metadata [8328 kB]
Get:29 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 Packages [1723 kB]
Get:30 http://archive.ubuntu.com/ubuntu noble-updates/main Translation-en [322 kB]
Get:31 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 Components [175 kB]
Get:32 http://archive.ubuntu.com/ubuntu noble-updates/main amd64 c-n-f Metadata [16.4 kB]
Get:33 http://archive.ubuntu.com/ubuntu noble-updates/universe amd64 Packages [1528 kB]
Get:34 http://archive.ubuntu.com/ubuntu noble-updates/universe Translation-en [313 kB]
Get:35 http://archive.ubuntu.com/ubuntu noble-updates/universe amd64 Components [386 kB]
Get:36 http://archive.ubuntu.com/ubuntu noble-updates/universe amd64 c-n-f Metadata [31.9 kB]
Get:37 http://archive.ubuntu.com/ubuntu noble-updates/restricted amd64 Packages [2547 kB]
Get:38 http://archive.ubuntu.com/ubuntu noble-updates/restricted Translation-en [583 kB]
Get:39 http://archive.ubuntu.com/ubuntu noble-updates/restricted amd64 Components [212 kB]
Get:40 http://archive.ubuntu.com/ubuntu noble-updates/restricted amd64 c-n-f Metadata [556 kB]
Get:41 http://archive.ubuntu.com/ubuntu noble-updates/multiverse amd64 Packages [32.1 kB]
Get:42 http://archive.ubuntu.com/ubuntu noble-updates/multiverse Translation-en [6816 kB]
Get:43 http://archive.ubuntu.com/ubuntu noble-updates/multiverse amd64 Components [948 kB]
Get:44 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 Packages [49.4 kB]
Get:45 http://archive.ubuntu.com/ubuntu noble-backports/main Translation-en [9288 kB]
Get:46 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 Components [7300 kB]
Get:47 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 c-n-f Metadata [368 kB]
Get:48 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 Packages [29.5 kB]
Get:49 http://archive.ubuntu.com/ubuntu noble-backports/universe Translation-en [17.9 kB]
Get:50 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 Components [18.5 kB]
Get:51 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 c-n-f Metadata [1444 kB]
Get:52 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 Components [216 kB]
Get:53 http://archive.ubuntu.com/ubuntu noble-backports/restricted amd64 c-n-f Metadata [116 kB]
Get:54 http://archive.ubuntu.com/ubuntu noble-backports/restricted amd64 Components [212 kB]
Get:55 http://archive.ubuntu.com/ubuntu noble-backports/multiverse amd64 Components [212 kB]
Get:56 http://archive.ubuntu.com/ubuntu noble-backports/multiverse amd64 c-n-f Metadata [116 kB]
Fetched 39.6 MB in 12s (3171 kB/s)
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
126 packages can be upgraded. Run 'apt list --upgradable' to see them.
shyleari@vassudevazipeta:~$ |
```

```
shyleari@vassudevazipeta:~ % + ~
Get:59 http://archive.ubuntu.com/ubuntu noble-updates/restricted amd64 Components [212 kB]
Get:60 http://archive.ubuntu.com/ubuntu noble-updates/restricted amd64 c-n-f Metadata [556 kB]
Get:61 http://archive.ubuntu.com/ubuntu noble-updates/multiverse amd64 Packages [32.1 kB]
Get:62 http://archive.ubuntu.com/ubuntu noble-updates/multiverse Translation-en [6816 kB]
Get:63 http://archive.ubuntu.com/ubuntu noble-updates/multiverse amd64 Components [948 kB]
Get:64 http://archive.ubuntu.com/ubuntu noble-updates/multiverse amd64 c-n-f Metadata [496 kB]
Get:65 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 Packages [48.4 kB]
Get:66 http://archive.ubuntu.com/ubuntu noble-backports/main Translation-en [9288 kB]
Get:67 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 Components [7300 kB]
Get:68 http://archive.ubuntu.com/ubuntu noble-backports/main amd64 c-n-f Metadata [368 kB]
Get:69 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 Packages [29.5 kB]
Get:70 http://archive.ubuntu.com/ubuntu noble-backports/universe Translation-en [17.9 kB]
Get:71 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 Components [18.5 kB]
Get:72 http://archive.ubuntu.com/ubuntu noble-backports/universe amd64 c-n-f Metadata [116 kB]
Get:73 http://archive.ubuntu.com/ubuntu noble-backports/restricted amd64 c-n-f Metadata [116 kB]
Get:74 http://archive.ubuntu.com/ubuntu noble-backports/restricted amd64 Components [212 kB]
Get:75 http://archive.ubuntu.com/ubuntu noble-backports/multiverse amd64 Components [212 kB]
Get:76 http://archive.ubuntu.com/ubuntu noble-backports/multiverse amd64 c-n-f Metadata [116 kB]
Fetched 39.6 MB in 12s (3171 kB/s)
Reading package Lists... Done
Building dependency tree... Done
Reading state information... Done
126 packages can be upgraded. Run 'apt list --upgradable' to see them.
shyleari@vassudevazipeta:~$ sudo apt install gcc
Reading package lists... Done
Building dependency tree... Done
Reading state information... Done
The following additional packages will be installed:
  cpp cpp-13 cpp-13-x86-64-linux-gnu cpp-x86-64-linux-gnu gcc-13 gcc-13-base gcc-13-x86-64-linux-gnu gcc-x86-64-linux-gnu libasan3 libasan8 libatomic
  libc-bin libc-dev-bin libdev-tools libc6-dev libgcc-13-dev libgcc-13-dev libgd3 libgnapi libheif-plugin-amdec
  libheif-plugin-aomenc libheif-plugin-libde265 libheif1 libhwasan0 libl1m1 libasan0 libepc3 libquadmath0 libtsan1 libubsan1 libxpm4
  linux-libc-dev locales manpages-dev rpcsvc-proto
Suggested packages:
  cpp-doc gcc-13-locales cpp-13-doc gcc-multilib make autoconf libtstool flex bison gdb gcc-doc gcc-13-multilib gcc-13-doc gdb-x86-64-linux-gnu
  glibc-doc libasan3 libasan8-nisplus libd7-tools libheif-plugin-x265 libheif-plugin-ffmpegdec libheif-plugin-jpegdec libheif-plugin-jpgenc
  libheif-plugin-j2kdec libheif-plugin-j2kenc libheif-plugin-ravie libheif-plugin-svtenc
The following NEW packages will be installed:
  cpp cpp-13 cpp-13-x86-64-linux-gnu cpp-x86-64-linux-gnu gcc gcc-13 gcc-13-base gcc-13-x86-64-linux-gnu gcc-x86-64-linux-gnu libasan3 libasan8 libatomic
  libc-dev-bin libc-dev-tools libc6-dev libcrypt-dev libde265-8 libgcc-13-dev libgd3 libgnapi libheif-plugin-amdec libheif-plugin-aomenc
  libheif-plugin-libde265 libheif1 libhwasan0 libl1m1 libasan0 libepc3 libquadmath0 libtsan2 libubsan1 libxpm4 linux-libc-dev manpages-dev
  rpcsvc-proto
The following packages will be upgraded:
  libc-bin libc6 locales
3 upgraded, 37 newly installed, 0 to remove and 123 not upgraded.
Need to get 12.6 MB/63.2 MB of archives.
After this operation, 181 MB of additional disk space will be used.
Do you want to continue? (Y/n) |
```

```
shylasri@vasudevkapetla:~$ gcc --version
gcc (Ubuntu 13.3.0-6ubuntu2~24.04) 13.3.0
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This is free software; see the source for copying conditions. There is NO
warranty; not even for MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.

shylasri@vasudevkapetla:~$ gcc sum_serial.c -o sum_serial
shylasri@vasudevkapetla:~$ ./sum_serial
Serial Sum: 2499999975000000.000000
Execution Time: 0.444841 seconds
shylasri@vasudevkapetla:~$ |
```

Task 3: OpenMP Parallel Loop

Objective: Parallelize the loop using OpenMP.

File: sum_openmp.c

```
#include <stdio.h>

#include <omp.h>

#define N 100000000

int main() {

    double sum = 0.0;

    double start = omp_get_wtime();

    #pragma omp parallel for reduction(+:sum)

    for (long i = 0; i < N; i++) {

        sum += i * 0.5;

    }

    double end = omp_get_wtime();

    printf("Parallel Sum: %f\n", sum);

    printf("Execution Time: %f seconds\n", end - start);

    printf("Threads Used: %d\n", omp_get_max_threads());

    return 0;

}
```

Compile:

```
&gt; gcc -fopenmp sum_openmp.c -o sum_openmp
```

```
shylasri@vasudevkazipeta:~$ nano sum_openmp.c
shylasri@vasudevkazipeta:~$ cat sum_openmp.c
#include <stdio.h>
#include <omp.h>

#define N 1000000000

int main() {
    double sum = 0.0;
    double start = omp_get_wtime();

    #pragma omp parallel for reduction(+:sum)
    for (long i = 0; i < N; i++) {
        sum += i * 0.5;
    }

    double end = omp_get_wtime();

    printf("Parallel Sum: %f\n", sum);
    printf("Execution Time: %f seconds\n", end - start);
    printf("Threads Used: %d\n", omp_get_max_threads());

    return 0;
}

shylasri@vasudevkazipeta:~$ gcc -fopenmp sum_openmp.c -o sum_openmp
shylasri@vasudevkazipeta:~$ ./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.104064 seconds
Threads Used: 16
shylasri@vasudevkazipeta:~$ |
```

Task 4: Thread Scaling Experiment

Run with different thread counts:

```
export OMP_NUM_THREADS=1
```

```
./sum_openmp
```

```
export OMP_NUM_THREADS=2
```

```
./sum_openmp
```

```
export OMP_NUM_THREADS=4
```

```
./sum_openmp
```

```
export OMP_NUM_THREADS=8
```

```
./sum_openmp
```

Record the readings in a below table:

Threads Execution Time (s)

Threads	Execution Time (s)
---------	--------------------

1	0.406154
---	----------

2	0.179729
---	----------

4	0.129804
---	----------

8	0.079485
---	----------

```
shylasri@vasudevkapeta:~$ gcc -fopenmp sum_openmp.c -o sum_openmp
shylasri@vasudevkapeta:~$ export OMP_NUM_THREADS=1
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.406154 seconds
Threads Used: 1
shylasri@vasudevkapeta:~$ |
```

```
shylasri@vasudevkapeta:~$ gcc -fopenmp sum_openmp.c -o sum_openmp
shylasri@vasudevkapeta:~$ export OMP_NUM_THREADS=1
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.406154 seconds
Threads Used: 1
shylasri@vasudevkapeta:~$ export OMP_NUM_THREADS=2
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.179729 seconds
Threads Used: 2
shylasri@vasudevkapeta:~$ |
```

```

shylasri@vasudevkapizipeta:~$ gcc -fopenmp sum_openmp.c -o sum_openmp
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=1
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.406154 seconds
Threads Used: 1
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=2
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.179729 seconds
Threads Used: 2
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=4
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.129804 seconds
Threads Used: 4
shylasri@vasudevkapizipeta:~$ |

```

```

shylasri@vasudevkapizipeta:~$ gcc -fopenmp sum_openmp.c -o sum_openmp
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=1
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.406154 seconds
Threads Used: 1
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=2
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.179729 seconds
Threads Used: 2
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=4
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.129804 seconds
Threads Used: 4
shylasri@vasudevkapizipeta:~$ export OMP_NUM_THREADS=8
./sum_openmp
Parallel Sum: 2499999975000000.000000
Execution Time: 0.079485 seconds
Threads Used: 8
shylasri@vasudevkapizipeta:~$ |

```

Task 5 — Speedup & Efficiency Calculation

Formula:

Speedup

$$S(p) = \frac{T_1}{Tp}$$

Efficiency

$$E(p) = \frac{S(p)}{p}$$

Where, $T_1 = 0.406154$ seconds

Observation

- Execution time decreases as threads increase.
- Speedup improves with thread count.
- Efficiency decreases when thread count increases due to overhead and resource sharing.

Threads	Time (s)	Speedup	Efficiency
1	0.406154	1.00	1.00
2	0.179729	2.26	1.13
4	0.129804	3.13	0.78
8	0.079485	5.11	0.64

Observation

Execution time decreases as threads increase.

Speedup improves with thread count.

Efficiency decreases when thread count increases due to overhead and resource sharing.

Task 6:

1. Why does OpenMP work well for this loop?

OpenMP works well because each loop iteration is independent and can be executed in parallel without affecting other iterations. The workload is evenly divided among threads, and the reduction clause safely combines partial results.

2. What happens if loop iterations are dependent?

If loop iterations are dependent, parallel execution can produce incorrect results because some iterations may require results from previous iterations. This leads to data races unless synchronization is added, which reduces performance.

3. Why does speedup stop improving after some threads?

Speedup stops improving due to thread creation overhead, synchronization costs, memory bandwidth limitations, and the finite number of CPU cores available on the system.

4. Is OpenMP suitable for multi-node systems? Why/why not?

No, OpenMP is not suitable for multi-node systems because it uses shared memory. Multi-node systems require distributed memory programming models such as MPI.

Observation:

In this experiment, OpenMP significantly reduced execution time by parallelizing an independent loop across multiple threads. As the number of threads increased, performance improved due to better CPU utilization. However, the speedup gradually saturated because of hardware limitations, thread management overhead, and memory access constraints. This shows that while OpenMP is highly effective for shared-memory parallelism, optimal performance depends on problem structure and system resources. OpenMP is best suited for multi-core, single-node systems with independent computations.