Programming Lab 3: Loop Parallelization with OpenMP

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Problem 3.1. The N-Body Simulation Problem

In the N-Body simulation problem, the positions and the velocities of a collection of mass particles are computed over a period of time. In this particular exercise, we will simulate the motion of massive objects such as planets that interact with one another only through gravitational forces. Thus, we will use Newton's second law of motion as well as his law of universal gravitation.

$$\mathbf{f}_{ij}(t) = -\frac{Gm_i m_j}{|\mathbf{r}_i(t) - \mathbf{r}_j(t)|^3}(\mathbf{r}_i(t) - \mathbf{r}_j(t)) \tag{1}$$

When an object i has position $\mathbf{r}_i(t)$ at time t and an object j has position $\mathbf{r}_j(t)$ at time t, then the gravitational force the object j exerts on the object i is $\mathbf{f}_{ij}(t)$, according to Eq. 1, where G is the gravitational constant ($6.673 \times 10^{-11} \frac{m^3}{kg \cdot s}$).

Algorithm 1 :N-Body Simulation

```
Initialize Data (m[1:n], r[1:n], v[1:n])
for each time step ΔT do
    for each Object i do
        Compute Total Force F_i on Object i
    for each Object i do
        Update Position r_i and Velocity v_i of Object i
```

Algorithm 2 is used to compute the total force exerted on each Object i.

Algorithm 2 :Compute Total Force on Object i

```
for each Object j do
    if i ≠ j then
        Δx = r_{i,x} − r_{j,x}
        Δy = r_{i,y} − r_{j,y}
        R = sqrt(Δx^2 + Δx^2)
        F_{i,x} = F_{i,x} − (G·m_i·m_j·Δx)/R^3
        F_{i,y} = F_{i,x} − (G·m_i·m_j·Δy)/R^3
```

Algorithm 3 is used to update the position and the velocity of each Object i over a sufficiently small period of time Δt.

Implement a serial algorithm for the N-Body problem described above. Analyze the running time complexity of the serial algorithm.

Problem 3.2. Parallelizing the N-Body Simulation Problem with OpenMP
Implement the N-Body Simulation Problem with OpenMP. Measure the running times of the parallel algorithm for different problem sizes and number of threads.

Algorithm 3 :Compute Total Force on Object i

1: **for** each Object j **do**
2: $\quad \mathbf{r}_{i,x} = \mathbf{r}_{i,x} + \mathbf{v}_{i,x} \cdot \Delta t$
3: $\quad \mathbf{r}_{i,y} = \mathbf{r}_{i,y} + \mathbf{v}_{i,y} \cdot \Delta t$
4: $\quad \mathbf{v}_{i,x} = \mathbf{v}_{i,x} + \frac{\mathbf{f}_{i,x}}{m_i} \cdot \Delta t$
5: $\quad \mathbf{v}_{i,y} = \mathbf{v}_{i,y} + \frac{\mathbf{f}_{i,y}}{m_i} \cdot \Delta t$