March 4, 2024

HPC LAB 6

1. Implementation of Conv2D operation in OpenMP.

Convolutional Neural Networks (CNNs) are a class of deep learning algorithms that are particularly useful for processing images. The Conv2D operation is a fundamental part of CNNs. It involves passing a filter (also known as a kernel) over an image and computing the dot product of the filter values and the original pixel values of the image.

In this task, you are given three images and three 3x3 filters. Your task is to implement the Conv2D operation for each image-filter pair and output the resulting feature maps.

The filters are as follows:

- **Filter 1 (Edge Detection Filter):** This filter detects edges in the image by highlighting the change in intensity of the pixels. The filter is as follows:
$$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$
- **Filter 2 (Edge Detection Filter):** This filter also detects edges but in a different direction compared to Filter 1. The filter is as follows:
$$\begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$
- **Filter 3 (Laplacian Filter):** This filter is used for edge detection and texture extraction. It highlights regions of rapid intensity change in an image. The filter is as follows:
$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Let's consider a simple 5x5 matrix as our input image and a 3x3 matrix as our filter. Here's how the Conv2D operation would work:

Input Image (5x5 Matrix):

$$\begin{bmatrix} 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 \end{bmatrix}$$

Filter (3x3 Matrix):

$$\begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix}$$

Step 1: Place the filter on the top-left corner of the image.

Step 2: Perform element-wise multiplication of the filter and the image section covered by the filter.

$$\begin{bmatrix} 1*1 & 0*1 & 1*1 \\ 0*0 & 1*1 & 0*1 \\ 1*0 & 0*0 & 1*1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Step 3: Sum up the results of the element-wise multiplication and place the result in the corresponding location of the output feature map.

$$1 + 0 + 1 + 0 + 1 + 0 + 0 + 0 + 1 = 4$$

So, the top-left element of the output feature map is 4.

Step 4: Slide the filter to the right by one pixel (also known as a stride) and repeat Steps 2 and 3. Continue this process until you've covered the entire width of the image.

Step 5: Once the entire width of the image has been covered, move the filter down by one pixel and repeat the process. Continue this until the entire image has been covered.

By repeating these steps, we can generate the entire output feature map. Note that because we're not using any padding and our stride is 1, the output feature map will be a 3x3 matrix (input size of 5 minus filter size of 3, plus 1).

2. How does the interaction between charged particles influence their movement?

Consider a simulation of charged particles. The movement of these particles is influenced by the interactions between them due to their charges. For the purpose of this simulation, we will ignore any gravitational interactions.

The simulation should proceed in time steps of 0.0001 seconds, and the final position of all the particles after 10 seconds should be determined.

The initial conditions for the simulation will be provided in a text file. This file will consist of three columns: the x-coordinate of the initial position of the particle, the y-coordinate of the initial position of the particle, and the charge it contains.

The net force acting on any particle is the vector sum of the forces due to all other particles. The direction of the force on a particle is towards the other particle if they have opposite charges, and away from the other particle if they have the same charge. The magnitude of the force is given by Coulomb's law:

$$F = k\frac{|q_1 q_2|}{r^2} \tag{0-1}$$

where F is the magnitude of the force, k is Coulomb's constant, q_1 and q_2 are the charges of the particles, and r is the distance between the particles.

Assume that the particles are initially stationary, i.e., the initial velocities in the x and y directions ($v_{x,0}$ and $v_{y,0}$) are both zero. The displacement of the particle in the x and y directions can be found using the equations of motion:

$$\Delta x = v_x \Delta t + \frac{1}{2} a_x (\Delta t)^2$$
$$\Delta y = v_y \Delta t + \frac{1}{2} a_y (\Delta t)^2$$

where Δx and Δy are the displacements in the x and y directions respectively, v_x and v_y are the velocities in the x and y directions respectively, a_x and a_y are the accelerations in the x and y directions respectively, and Δt is the time step.

The velocities in the x and y directions at any time can be found using the equations:

$$v_x = v_{x,0} + a_x \Delta t$$
$$v_y = v_{y,0} + a_y \Delta t$$

The accelerations in the x and y directions are given by the net force acting on the particle (obtained from Coulomb's law) divided by the mass of the particle (assume the mass is same for all particles):

$$a_x = \frac{F_x}{m}$$
$$a_y = \frac{F_y}{m}$$

where F_x and F_y are the components of the net force in the x and y directions respectively, and m is the mass of the particle.