*J. H. Walther*
*S. Martin*
*ETH Zentrum, CLT*
*CH-8092 Zürich*

Fall semester 2022

# Set 5 - MPI Part II

Issued: November 23, 2022
Hand in (optional): December 7, 2022 08:00

**Grading:** To get full credits solve **all** of the questions.

## Question 1: Diffusion (100 points)

The diffusion of a substance can be described by the equation

$$\frac{\partial c(x,y,t)}{\partial t} = D\left(\frac{\partial^2 c(x,y,t)}{\partial x^2} + \frac{\partial^2 c(x,y,t)}{\partial y^2}\right),$$

where $c$ is the concentration of the substance at position $(x,\ y)$ and at time $t$, and $D$ is the diffusion constant. The diffusion process happens in the domain $|x| < L/2$ and $|y| < L/2$. The concentration is zero on the boundaries of the domain. The initial concentration is

$$c(x,y,0) = \begin{cases} 1, & \text{if } |x| < L/4 \text{ and } |y| < L/4, \\ 0, & \text{otherwise.} \end{cases}$$

a) The skeleton code solves the equation on a uniform grid using a central finite difference scheme in space and forward Euler time integration. Parallellize the code by filling parts marked by `TODO` in the functions `advance` and `main`. Use a tiling decomposition scheme (i.e., distribute the rows evenly to the MPI processes). How to run the code:

- `make` to compile the code
- `make run` to run single core (please not in the login node on euler!). If not locally on the laptop, use `sbatch launch_single.sh` to submit a job via slurm.
- to run multicore use: `mpirun -n x ./diffusion D L N`. You can also use `sbatch launch_single.sh` to submit a job via slurm.

b) For a given time compute the integral of $c(x,y,t)$ over the domain (total ammount of the substance). Fill the missing MPI parts in `compute_diagnostics`, and plot the result as a function of time using $D = 1$, $L = 2$ and $N = 100$. When run correctly, the code will output file called `diagnostics.dat`. To plot this data use `python plot_diagnostics.py` (module load python).

c) For a given time compute the histogram of $c(x,y,t)$ in the function `compute_histogram` by implementing the missing MPI parts marked by `TODO`, and plot or print the resulting histogram for $t = 0.5$ using $D = 1$, $L = 2$ and $N = 100$.

d) Suggest other ways to divide the real-space domain between processes with the aim of minimizing communication overhead. Prove your argument by computing the message communication size for the tiling domain decomposition and for your suggestion.

e) Make a strong and weak scaling plot up to 48 cores. Justify what is happening in your plots. Make at least five different numbers of cores runs (e.g. [1, 12, 24, 36, 48] or [1, 2, 4, 8, 16]). For the strong scaling plot use: N = {1024, 2048, 4096, 8192}, in other words, plot at least four lines (if too slow use smaller N's). For the weak scaling plot, use N = 1024 and N = 2048 (if those are taking too long use smaller N's). Use D = 1, L = 2 and modify the number of timesteps `step = 100`. Do not forget to state which CPU you ran the tests on! You can use the `run.sh` script to run for different number of cores. On euler use `run.sh` via `sbatch launch.sh`. Draw the plots either directly on the paper (which is the way you will do it on the exam). Or use any desired ploting scripts.