

```

subroutine godunov(idim,dt)
  use Hydra_commons
  use Hydra_const
  use Hydra_parameters
  use Hydra_util
  use Hydra_work_space
  use my_own_module
  implicit none

  ! Dummy arguments
  integer(kind=prec_int), intent(in) :: idim
  real(kind=prec_real),  intent(in) :: dt
  ! Local variables
  integer(kind=prec_int) :: i,j,im
  real(kind=prec_real)  :: dtdx

```

```

! constant
dtdx=dt/dx

```

```

! Update boundary conditions
call make_boundary(idim)
if (idim==1)then

```

```

  ! Allocate work space for ID sweeps
  call allocate_work_space(imin,imax,ns=1)

  do j=lower-2, upper-2 ! was jmin=2,jmax=2

```

```

    ! Gather conservative variables
    do i=imin,imax
      u(i,ID)=uold(i,j,ID)
      u(i,IV)=uold(i,j,IV)
      u(i,IP)=uold(i,j,IP)
    end do
    if(nvar>4)then
      do im = 5,nvar
        do i=imin,imax
          u(i,im)=uold(i,j,im)
        end do
      end do
    end if

```

```

    ! Convert to primitive variables
    call constopr(u,q,c)

```

```

    ! Characteristic tracing
    call trace(q,dq,c,qm,qp,dtdx)

```

```

    do im = 1,nvar
      do i=1,ns-1
        qleft(i,im)=qm(i-1,im)
        qright(i,im)=qp(i+2,im)
      end do
    end do

```

```

    ! Solve Riemann problem at interfaces
    call riemann(qleft,qright,qpmv, &
      & rl,ul,pl,cl,wr,pr,cr,wr,rs,vs,ps,cs,ws, &
      & rstar,vstar,ptstar,cstar,qpm,spin,spout, &
      & vshock,frac,scr,delp,pold,ind,ind2)

```

```

  ! Compute fluxes

```

# Parallelizing The Hydro Code

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# Hydro Code Explained

The hydro code is a simulation of a fluid or gas in an enclosed system. The initial conditions are set as to generate an unperturbed, homogeneous environment. Then, one can introduce points of higher or lower pressure or density to imitate an explosion or jet. The code then calculates the propagation of this perturbation using Godunov's method and outputs each frame as a single file, which can be used to create an animation.

There are five main components with different functionality to this Fortran based code. They are:

- `main.f90`
  - calls `init_hydro` to initialize the grid with the initial conditions
  - executes the main time loop by calling
    - \* `output` to generate output data
    - \* `cmpdt` to compute the time step
    - \* `godunov` to calculate the fluid dynamics
- `module_hydro_principal.f90` contains the subroutines
  - `init_hydro`
  - `cmpdt`
  - `godunov` which calls
    - \* `make_boundary` to set the upper, lower, left and right boundaries of the grid
    - \* `allocate_work_space/deallocate_work_space` to (de)allocate space in the memory
    - \* other subroutines for calculation purposes
- `module_hydro_utils.f90` contains
  - `make_boundary`
  - other subroutines
- `module_hydro_IO.f90` contains the subroutines
  - `read_params` to read the parameters from the `input.nml` file
  - `output`
- `module_hydro_commun.f90` contains
  - `allocate_work_space/deallocate_work_space`
  - various other subroutines, mainly to define the variables used elsewhere in the code

Additionally, there are several input files to set the grid size, initial conditions, etc.

# Parallelization Techniques

## MPI

### Introduction

MPI stands for *message passing interface*. This refers to the fact that parallel computing occupies multiple CPUs to fasten up the execution of a code. As these CPUs work independently and with their own associated memory, they will have to communicate in some way; this is what MPI does.

The advantage of MPI over other libraries is that one has much more control over how the code is parallelized. The programmer can explicitly choose how the different cores communicate to each other and which information they share.

On the other hand, this freedom makes parallelizing a code a much more complex problem than it could be with other libraires. It requires quite a deep understanding of how the code works to know where and what to adjust.

### Parallelization Process

The main points that needed to be adjusted were the following:

- Workspace allocation
- Time step computation
- Godunov boundaries
- Communication between boundaries
- Output formatting

### Results

The plots for the respective runtimes of both the strong and weak scaling can be seen below:

The simulation was run from 1 to 36 cores 10 times each.

The settings for the strong scaling were the following:

$t_{\text{end}}$	$nx$	$ny$	$dx$
50.0	50	9000	0.08

The settings for the weak scaling were the following:

$t_{\text{end}}$	$nx$	$ny$	$dx$
50.0	50	300	0.08

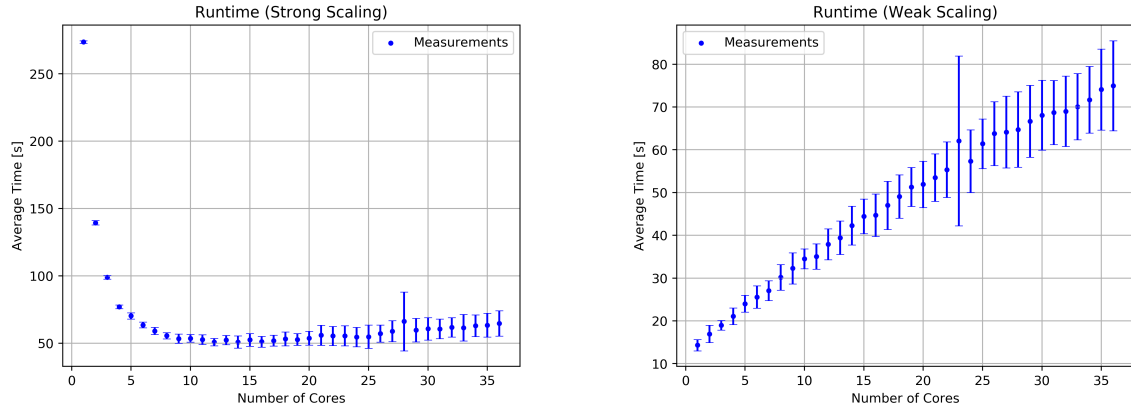


Figure 1: Respective runtimes for strong and weak scaling

Note that the  $n_x$  remained unchanged during the weak scaling run, but  $n_y$  increased linearly with the number of processes involved,  $n_y = n_y \cdot (\text{number of processes})$ .

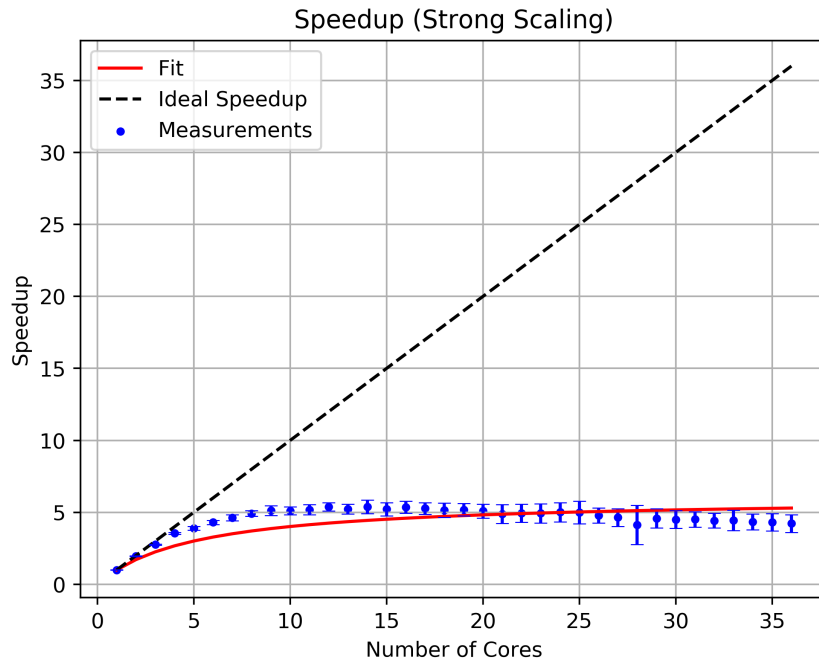


Figure 2: Speedup for strong scaling

The fit for the strong scaling is done with the following formula (Lecture 5):

$$\frac{1}{\alpha + \frac{1-\alpha}{N}} \quad (1)$$

Where  $\alpha$  represents the non-parallelized fraction of the code, and  $N$  is the number of processes.

This yields the following value:

$$\alpha = \quad (2)$$

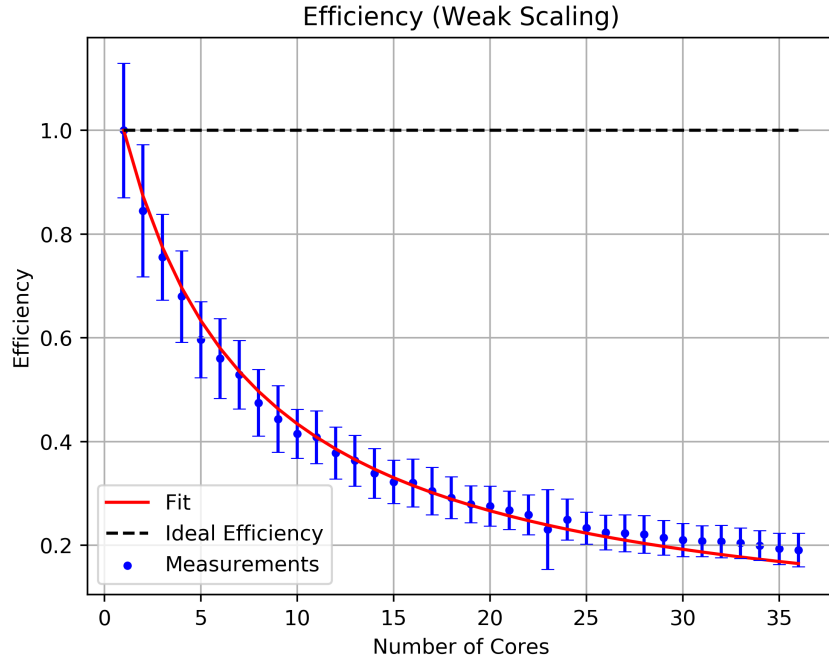


Figure 3: Speedup for weak scaling

The formula for the fit for the weak scaling can be derived quite easily. Again, take  $\alpha$  to be the non parallelized fraction of the code. Then,  $T_p(N)$ , the time needed for the parallel code, is

$$T_p(N) = N \cdot (1 - \alpha) + \alpha$$

So then,

$$\text{Speedup}(N) = \frac{T_s(N)}{T_p(N)} = \frac{T_s}{T_p(N)} = \frac{1}{(1 - \alpha) \cdot N + \alpha}$$

Fitting this over the data yields:

$$\alpha = \quad (3)$$

## **Other Techniques**

### **OpenMP**

### **MPI - OpenMP Hybrid**

## **Discussion**

As can be seen in Figure 1, the standard deviation on some of the runtimes can be quite big. This is mainly due that the whole run (going from 1 to 36 processes) was only performed 10 times. If one of these times is abnormally high or low, averaging over only 10 values will not suppress this spike well enough.

## **Conclusion**