Application of Cross-Reference Framework CoToCoA to Global and Local Simulations of Planetary Magnetospheres

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In this study, we have introduced the Code-to-Code Adapter (CoToCoA) library to couple the magnetohydrodynamic (MHD) simulation and the Electron Hybrid simulation of planetary magnetospheres. CoToCoA has been developed newly to connect the different simulation codes "easily." The design concept of CoToCoA is that we do not add modifications to each simulation codes as possible without data transfer, and we do not need to know the referred simulation code without data format. In the magnetosphere, the MHD simulation can treat macro-scale phenomena, and the Electron Hybrid simulation can represent micro-scale phenomena. These multi-scale phenomena are physically related to each other, however the coupling simulation of these scales have not been performed until recently. With CoToCoA, we have been developing the cross-reference simulation of macro and micro scales in the magnetosphere. In the exascale computing era, it will be possible to run the coupling simulations in multi scales and regions. Thus, we have evaluated the performance of cross-reference simulation using CoToCoA on the massively parallel computer system (up to 1024 nodes).

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1. INTRODUCTION

Magnetosphere is multi scale environment

Many phenomena of MHD scale to particle scale occurs in the magnetosphere. In addition, there are several region as ionosphere, plasmasphere, etc. The physics in these phenomena and regions are quite different, thus we study them differently.

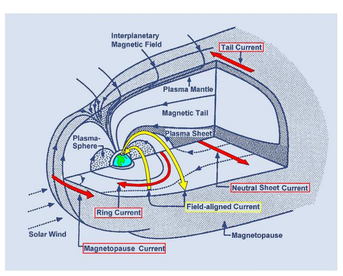


Fig.1. A sketch of the magnetosphere (modified from Kivelson and Russel [1995])

Multi scale/region coupling

However, the phenomena in the different scales are related each other. The different regions are not disconnected in the real space. Thus the study of coupling between the scale or regions are conducted. In the development of coupling different simulations, there are a lot of difficulties (learning the simulation method, understanding the parameter name and dialect of programmer, etc.)

That is, **the simulation codes developed by others are extremely hard to understand!**

Motivation -Connect the code easily!

Now we develop the Cross-Reference Numerical Simulation Framework not understanding the other's code and with the minimal change to the codes.

In this study **we have implemented the calculation of magnetic filed line from the MHD simulation and transfer the field line data to the Electro-Hybrid (EH) simulation code using the framework**.

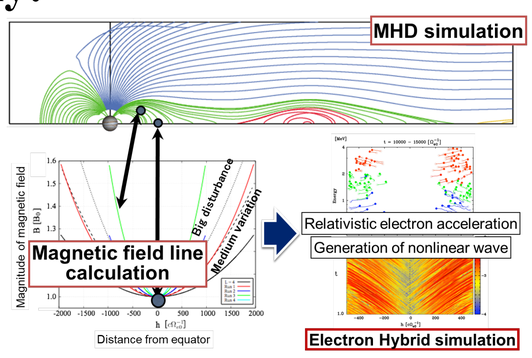


Fig. 2. Schematic diagram of coupling between MHD simulation and EH simulation

2. CoToCoA Framework

CoToCoA(Code To Code Adapter) is the library can connect the code to other code very easily!

The features of CoToCoA are

- less changes of each code → **each code can run in each process group**
- basically not required to know the process rank of other code when the data is transferred → **do not need to understand other code**
- now MPI based and Fortran and C supported

There are three interfaces to connect the codes

- Requester : Send calculation request to Coupler
- Coupler : Receive the request from Requester then transfer the data to selected Worker
- Worker : Run the program according to request from Coupler

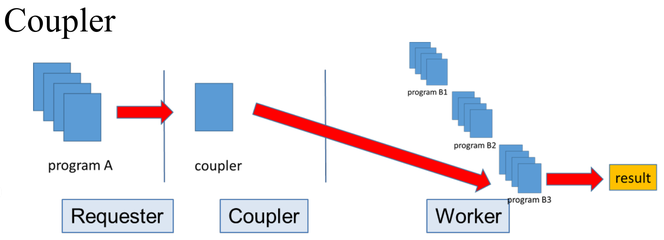


Fig. 3. Data transfer in CoToCoA framework.

Coupler enables easy connect!!

Send request from Requester to Coupler

Send an integer array (arbitrary size) for Calculation step and area, etc.

```
subroutine CTCAR_sendreq(dataint, dataintnum)
  integer(kind=4) :: dataintnum
  integer(kind=4), dimension(1:*) :: dataint
```

*These are available on every process of Requester

*There are extend routine: Send and Receive an integer array + double precision real array

Receive request on Coupler

Case of only integer array from Requester

```
subroutine CTCAC_pollreq(reqinfo, fromrank, dataint, dataintnum)
  integer(kind=4),dimension(CTCAC_REQINFOITEMS) :: reqinfo
  integer(kind=4) :: fromrank, dataintnum
  integer(kind=4),dimension(1:*) :: dataint
```

reqinfo: request information to worker (this is used by enqueue)
fromrank: rank number of send on Requester (this is defined by library)

Enqueue routine on Coupler

Case of only integer array from Requester

```
subroutine CTCAC_enqreq(reqinfo, progid, dataint, dataintnum)
  integer(kind=4),dimension(CTCAC_REQINFOITEMS) :: reqinfo
  integer(kind=4) :: progid, dataintnum
  integer(kind=4),dimension(1:*) :: dataint
```

*There are extend routine: Enqueue an integer array + double precision real array

reqinfo: request information from Requester, progid: program number

Receive request on Worker

Case of only integer array from Coupler

```
subroutine CTCAW_pollreq(fromrank, dataint, dataintnum)
  integer(kind=4) :: fromrank, dataintnum
  integer(kind=4), dimension(1:*) :: dataint
```

*There are extend routine: Receive an integer array + double precision real array

Complete request ack on Worker

```
subroutine CTCAW_complete()
```

Read the data in Requester from Coupler/Worker like MPI_get

Register data to area ID

Case of double precision real array

Requester

```
subroutine CTCAR_regarea_real8(base, size, areaid)
  real(kind=8), dimension(1:*) :: base
  integer(kind=4) :: size
  integer(kind=4) :: areaid
```

we also prepare the "_int (integer)", "_real4(single precision real)"

Coupler

```
subroutine CTCAC_regarea_real8(areaid)
```

Worker

```
subroutine CTCAW_regarea_real8(areaid)
```

Read the data of Requester

Case of double precision real array we also prepare the "_int (integer)", "_real4(single precision real)"

Coupler

```
subroutine CTCAC_readarea_real8(areaid, reqrank, offset, size, dest)
  integer(kind=4) :: areaid, reqrank, offset, size
  real(kind=8), dimension(1:*) :: dest
```

Worker

```
subroutine CTCAW_readarea_real8(areaid, reqrank, offset, size, dest)
```

Example to use CoToCoA

Coupler reads the data of Requester and transfer it to Worker

Requester

```
call CTCAR_init()
! Initialization part
call CTCAR_regarea_real8( &
     data, size, areaid)
do step = 1, nsteps
!  main calculation part
  call CTCAR_sendreq(dataint, &
       dataintnum)
end do
call CTCAR_finalize()
```

Coupler

```
call CTCAC_init()
! Initialization part
call CTCAC_regarea_real8(areaid)
do while
  call CTCAC_pollreq(reqinfo, fromrank, &
       dataint, dataintnum)
  if (CTCAC_isfin()) exit
! select the program of Worker and rank, offset
! calculation part
  call CTCAC_readarea_real8(areaid, rank, &
       offset, size, data)
  call CTCAC_enqreq_withreal8(reqinfo, progid, &
       dataint, dataintnum, data, size)
end do
call CTCAC_finalize()
```

Worker

```
call CTCAW_init(progid, procsperreq)
call CTCAW_regarea_real8(areaid)
do while
  call CTCAW_pollreq_withreal8( &
       fromrank, dataint, dataintnum, &
       data, size)
  if (CTCAW_isfin()) exit
! Initialization part
! main calculation
  call CTCAW_complete()
end do
call CTCAW_finalize()
```

3. PERFORMANCE EVALUATIONS

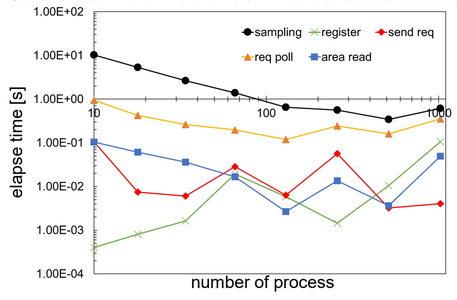
Implementation Smooth connect of MHD code +α

1. The parallel MHD simulation code (as Requester) calculates the magnetosphere.
2. The calculation code of magnetic filed line (as Coupler) read the magnetic field data from the MHD simulation in running. Note we need to know the magnetic field is located which process rank of MHD simulation
3. Then the field line data is transferred to the EH simulation code (as Worker)

Evaluation environment with Skylake Xeon Cluster (ITO)

Strong scaling

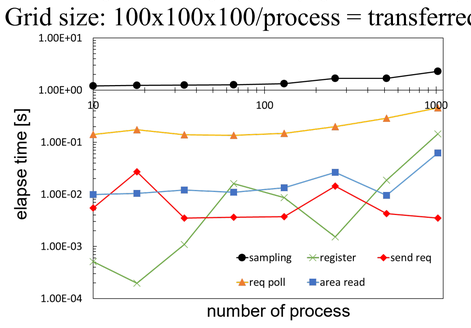
10~66 processes parallel (1 process/node)
Grid size: 400x400x400 = transferred data 0.7~91MB



The elapse times of sampling, req poll and area read decrease. Send req is not stable and register time increases in relative to the number of process.

Weak scaling

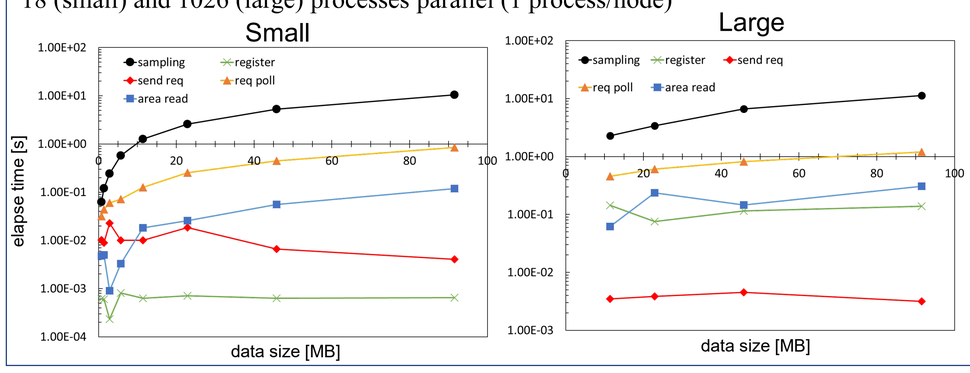
10~1026 processes parallel (1 process/node)
Grid size: 100x100x100/process = transferred data11.4 MB



The elapse times of sampling, area read and poll req are not changed. Send req is unstable. Register is also unstable but increases in proportion to the number of process.

Data size scaling

18 (small) and 1026 (large) processes parallel (1 process/node)



With the constant number of parallel and increase of data size, the elapse times of sampling, req poll and area read increase. The increase of data does not affect to send req and register.

4. SUMMARY

The main concepts of this framework are minimal modifications to the simulation codes and not need to know the referred simulation code without data format. These concepts allows for many simulation codes to use this framework. When coupling the magnetic filed line calculated from MHD simulation with Electron-Hybrid simulation, we can implement the parallel numerical code easily using the CoToCoA framework.
The performance evaluation of connecting the MHD code to the Electron-Hybrid code shows the very small overhead time. This framework can apply the simulation of planetary magnetosphere with the moon.