

# LSMearth and GeoFEM Coupling Analysis

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## Abstract

Earthquake processes involve complex phenomena and depend on fault dynamics. Different complex phenomena that occur at various scales control the fault dynamics. Using numerical simulation, results of laboratory experiments can be extrapolated to fault behaviour. Conceptual developments in understanding the physics of earthquakes combined with advances in numerical simulation methodology and High Performance Computing, make it possible to develop a new tool for earthquake studies. Observations made during laboratory experiments can be extrapolated using numerical simulations. Hence, numerical simulations provide a clue on the scalability of laboratory results and are a means to improve understanding on how such micro-scale processes in a gouge layer affect the macroscopic behavior of a fault zone. The interface being developed between the software system developed at QUAKEs (LSMearth) (Mora, *et al.*, 1999[1], Place and Mora, 2000[3]), and a finite-element based software system - GeoFEM (Iizuka, *et al.*, 1999[2]) will enable simulation of processes occurring at the microscopic scale using the particle-based model (LSMearth) and simulation of processes occurring at the macroscopic scale, such as plastic deformation and wave propagation, using the finite-element method (GeoFEM). Using this approach, the effects of microscopic phenomena on the macroscopic behavior of a large-scale fault system can be studied. This hybrid method will also extend the resolution of numerical experiments of fault zone behavior by allowing more efficient simulation of those parts of models well approximated as a continuum such as elastic regions outside the gouge zone. This paper shows the conceptual design for an interface and some computational results between LSMearth and GeoFEM.

## Conceptual design

### The physical interface

The exchange of physical values between the two models is done through the fault zone boundaries between the models. Forces and displacements are exchanged between particles of LSMearth and Nodes of GeoFEM along the fault zone boundaries.

## Scaling

During preliminary experiments, the same scale is used for both models. Hence, each node along the fault zone boundaries correspond to a particle in LSMearth. Exchange of data is performed between these nodes and particles. In the future, when using different scale for GeoFEM and LSMearth, interpolation will be required between the particles and the nodes along the fault zone boundaries. This will allow to use a much smaller scale for the LSMearth model than for the GeoFEM method. Hence, micro-physics occurring at the rock grain scale will be simulated with LSMearth while macroscopic phenomena (such as elastic deformation and wave propagation) are simulated with GeoFEM.

## Transfer of forces and deformations

To transfer forces and deformation between the models, displacements occurring in the LSMearth model are input at the nodes of the GeoFEM mesh (cf. Figure 1). From the displacements, deformations occur in the GeoFEM mesh, the traction forces can then be input in the LSMearth model by applying the force to corresponding particle.

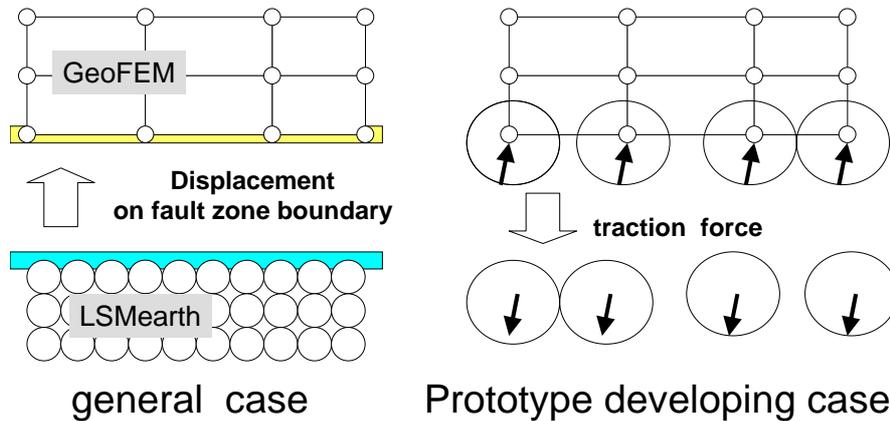


Figure 1: Physical interface

## Implementation

The implementation of the hybrid model consists of developing a GeoFEM main program (termed job controller) that controls the time evolution and call for the two models. Exchange of data is controlled by the job controller and is performed using a coupler. The job controller is designed as a GeoFEM main module and based on the GeoFEM-fault analysis module, which allows the access of GeoFEM's functions.

## The job controller

The time evolution of the hybrid model is controlled by the job controller which is written in Fortran90. The function of the job controller is (1) to initialize the models and the coupler and (2) to perform the time loop of GeoFEM and LSMearth. During the initialization, when calling the subroutine `init_coupler()`, connections between nodes of the GeoFEM mesh and particles of LSMearth are specified.

```

Program HModel
  call init_lsm_geofem()
  call init_geofem()
  call init_lsm()
  call init_coupler()

  do /* Time step control for GeoFEM */
    call DoGeoFem()
    do /* Time step control for LSM */
      call DoLSM()
    until end of GeoFEM time step
  until end of simulation
end

subroutine DoGeoFEM
  call get LtoG()
  call load CtoG()
  call dynamic contact()
  call save GtoC()
  call put GtoL()
end

subroutine DoLSM
  call get GtoL()
  call load CtoL()
  call LSMearth oneStep()
  call save LtoC()
  call put LtoG()
end

```

## The coupler

The coupler (cf. Figure 2) is the only module which has access to both the GeoFEM data space and the LSMearth data space. To combine the two data space of GeoFEM and LSMearth, a copy of the models data is placed in the coupler using only "save" and "load" subroutines(GtoC, CtoG). These subroutines have only access to the coupler data space. Model data can be transfer and interpolate from one model to the other using "get" and "put" subroutines. These subroutines have only access to the coupler data space.

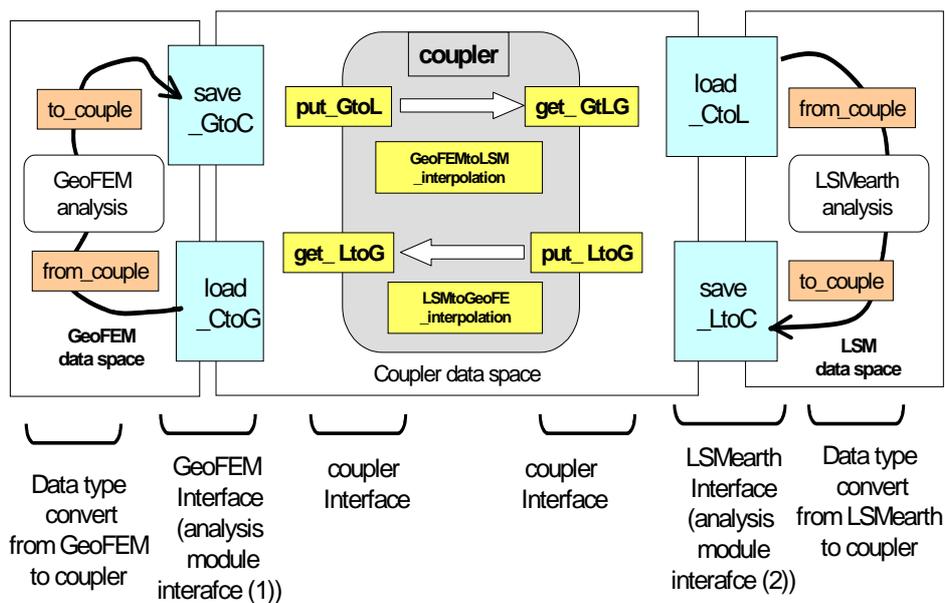


Figure 2: coupler system configuration

## The GeoFEM interface and the LSMearth interface

Because the job controller is based on the fault analysis module and LSMearth is written in C++, the LSMearth data and subroutines cannot be accessed directly. Hence, a C-interface is required to export LSMearth data and subroutines. Furthermore, to keep the modularity of LSMearth, a module in LSMearth, termed GeoFEM data exchange module, is created from which the two subroutines loadCtoL and saveLtoC (cf. Figure 2) can access LSMearth data or subroutines.

### The LSMearth C-interface

Because the GeoFEM is written in Fortran90 and LSMearth in C++, a C-interface is required to call C++ functions from a Fortran program.

## Conclusion

The implementation of the interface involves the development of a job controller, a coupler and a GeoFEM data exchange module in LSMearth. Ultimately the coupler interface can operate through a message-passing interface allowing the use of different super-computer architectures. The interface GeoFEM-LSMearth will allow multi-scale simulations of large-scale fault systems and the dynamics of earthquakes to be performed.

## References

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