Large-Scale Earthquake Rupture Simulations Using a Hybrid Method

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ABSTRACT

Earthquakes naturally occur around the world and large events might induce severe damages to the society. A complete understanding of earthquake physics requires comprehensively recorded ground motions close to those foci. Unfortunately, seismic stations are sparsely distributed and number of the stations is quite limited. However scientists could utilize numerical simulations to help understand the earthquake phenomena and make predictions for the future in term of the knowledge on factors such as faulting, geological settings.

We use the rate and state-dependent fault properties to simulate the earthquake ruptures using the XSEDE computing facilities in this study. The current rupture model, RSQSim, uses 3D boundary elements to discretize the fault surface. Earthquakes initiate at some elements, dependent on the stressing conditions, and propagate toward other elements using the interaction matrix. The central feature of this model is the use of event-driven computational steps as opposed to time stepping at closed spaced intervals to speed up. The memory per MPI process used in this parallel implementation is approximately expressed as follows:

$$(584*N)+(\frac{16*N^2}{np})+(8*np+40*nEq)\ \ bytes$$

where N is the number of elements, np is the number of MPI processes and nEq is the number of earthquakes desired. It is clear the memory requirement increases with the squared number of elements (second term, representing the element interactions) and the memory requirement per process is easy to exceed the usable memory per core, for example, 1.3GB per core on Kraken for two million fault elements. It is seen that while the number of MPI processes increases, the first term appears to be comparable to the second term. To improve the solution bandwidth with a large number of elements on the existing computing facilities, we use the hybrid method MPI +OPENMP to reduce the effect of the first term by grouping many cores to accommodate one MPI process so as to reduce the number of MPI processes consequently. This method certainly enhances the solution bandwidth, for example, making possible the simulations of 2 million elements over Kraken.

The RSQSim computational algorithm flow per transition loop may be sketched as

1. find local minimum dt for transitions
2. find global minimum dt
3. advance states

where dt is the time step. The critical part is to find the global minimum for dt (MPI_Allreduce) and thus the collective operation is definitely involved and very expensive with a large number of cores (strong scaling behaves well except for the global operation part). Therefore another benefit using the hybrid method is to greatly reduce the intra-process communications.

An example calculation was performed for earthquake occurrence by the fault system in 63419 years. The fault patch is 3km x 3km and the calculation was performed with 128 cores in 1.5 hours for this simple model. A small-sized fault element is essential to capture the effect of localized asperity zones that influence the slip behavior in the region, and is also more accurate in simulating the interactions among a system of faults such as rupture jump-overs between faults. For the purpose to better improve our understanding and make predictions of the behavior of the complex system, such as the all-California fault system including the active San Andreas Fault, powerful computing facilities such as Kraken, Blue Waters, are required to characterize the details of the fault element behavior and address the ensuing seismicity that might be changed by a sequence of earthquakes of different magnitudes in the region.