Resource-Efficient Simulation of Tsunami Wave Propagation on Parallel Computers

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Simulation of wave propagation is one of the most important tasks in studying tsunamis. For cross-ocean tsunamis, there are two immediate computational challenges. First, the size of the vast computational domain requires a large number of degrees of freedom. Second, local regions with difficult bottom topography require more sophisticated mathematical models than the linear shallow water wave model, therefore the need for unstructured meshes and implicit numerical schemes. In light of future tsunami warning systems, these two challenges have to be addressed in a computationally effective way.

Parallel computing is obviously the approach to handling large numbers of degrees of freedom. Many implicit numerical algorithms for solving partial differential equations can also incorporate parallelism. However, the computational resources of a parallel computer are limited in view of the ever increasing computational need, therefore should be utilized efficiently. In connection with tsunami wave propagation, it will be a waste to use homogeneously fine mesh resolution, advanced mathematical model and sophisticated numerical method everywhere over the entire ocean.

We argue for a computational strategy that is based on subdomains and thereby suitable for parallel computers. Originally inspired by the simple and elegant overlapping domain decomposition methods for solving linear systems, we allow the subdomains to adopt different mathematical models, different computational meshes, different numerical methods, and even different sequential software codes. Efficiency arises from using advanced models and high resolution only in areas where needed. The strategy not only enables parallel computing, but also allows rapid development of a hybrid wave propagation simulator based on existing sequential wave propagation codes. As mentioned earlier, the linear shallow water wave model is not sufficient for the entire ocean. More advanced mathematical models, such as the weakly dispersive and weakly nonlinear Boussinesq models, should be used in local regions where necessary. Scores of sequential software codes already exist for different models and numerical methods, and they should be reused as much as possible in a parallel setting. In a sense, the subdomains collaborate with each other but each may have its own mathematical, numerical and programming style.

In respect of implementation, object-oriented programming can help to set up a generic framework where the subdomain solvers are all assumed to have a standard interface including functions for solving a local problem and providing solutions in its overlapping zones. Existing sequential wave simulators have to be “wrapped up” with this standard interface, and object-oriented programming is a suitable tool for achieving this goal. The resulting parallel tsunami wave propagation simulator can allow “plug and play” at run-time to pick desired local solvers from a collection of subdomain solvers extended from existing sequential codes.

As an example we will show how a legacy Fortran77 code using finite differences and uniform meshes can join force with a modern C++ solver using finite elements and unstructured meshes to simulate the 2004 Indian Ocean Tsunami on parallel computers.