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Particle Methods: Past, Present and Future

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Abstract

Particle methods were first developed to handle the advection term in the equations of motion of fluids. They can do this easily because the particle trajectories are the characteristics of the hyperbolic part of the equations (the derivative following the motion), and the particles carry the fluid properties as they move. The equations of motion have other terms involving the spatial derivatives and these were originally calculated using a grid as in the Particle in Cell method (PIC) due to Harlow. A related method due to Eastwood is the EPIC method where virtual particles are found each time step with the property that they will arrive exactly on a node or vertex at the end of the step. This method called the quasi-lagrangian method in atmospheric sciences. A different method, and the one I shall talk about, is Smoothed Particle Hydrodynamics or SPH. In this method the spatial derivatives are calculated directly from the particles using a simple interpolation. The resulting equations of motion look like the equations of molecular dynamics and SPH can therefore be considered as a valid way of approximating the continuum equations or as a model of the underlying molecular dynamics. The advantage of working directly with the particles is that when splash or fragmentation occurs it is easy to follow the transition from the continuum to the fragmented state. The original SPH calculations were applied to astrophysics, especially star formation, where there are huge changes in density, and a great deal of the space in which the stars move is empty of matter. Because most of the action is where the particles are it is efficient to work directly with the particles and this makes SPH codes very efficient. SPH can be generalized easily to adjust the resolution as the particles move together in a region of increasing density. No other method has this simplicity. Further improvements were associated with deriving the equations of motion from a Lagrangian which led to improved conservation properties. To extend the method to nearly incompressible fluids such as water, the only change required is to use an equation of state which is sufficiently stiff to make the density fluctuations negligible. In addition rigid boundaries must be included and this has been done by either using boundary force particles, or by using ghost particles. Free surfaces do not need a special treatment. With these techniques it has been possible to simulate waves breaking on beaches, dam breaks and a wide range of problems involving rigid bodies moving in one or more fluids and, more exotically, special effects in movies. In my presentation I will describe many of these applications. In particular I will describe new work on the swimming of linked rigid bodies which opens up the detailed application of SPH to swimming robots and swimming fish, even those that leap out of the water. The interested reader will find an extensive discussion of the theory in a recent review (Monaghan, Reports on Progress in Physics ,2005).