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A heterogeneous and parallel computing framework for high-resolution hydrodynamic simulations

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Shock-capturing hydrodynamic models are now widely applied in the context of flood risk assessment and forecasting, accurately capturing the behaviour of surface water over ground and within rivers. Such models are generally explicit in their numerical basis, and can be computationally expensive; this has prohibited full use of high-resolution topographic data for complex urban environments, now easily obtainable through airborne altimetric surveys (LiDAR).

As processor clock speed advances have stagnated in recent years, further computational performance gains are largely dependent on the use of parallel processing. Heterogeneous computing architectures (e.g. graphics processing units or compute accelerator cards) provide a cost-effective means of achieving high throughput in cases where the same calculation is performed with a large input dataset. In recent years this technique has been applied successfully for flood risk mapping, such as within the national surface water flood risk assessment for the United Kingdom. We present a flexible software framework for hydrodynamic simulations across multiple processors of different architectures, within multiple computer systems, enabled using OpenCL and Message Passing Interface (MPI) libraries. A finite-volume Godunov-type scheme is implemented using the HLLC approach to solving the Riemann problem, with optional extension to second-order accuracy in space and time using the MUSCL-Hancock approach.

The framework is successfully applied on personal computers and a small cluster to provide considerable improvements in performance. The most significant performance gains were achieved across two servers, each containing four NVIDIA GPUs, with a mix of K20, M2075 and C2050 devices. Advantages are found with respect to decreased parametric sensitivity, and thus in reducing uncertainty, for a major fluvial flood within a large catchment during 2005 in Carlisle, England. Simulations for the three-day event could be performed on a 2m grid within a few hours. In the context of a rapid pluvial flood event in Newcastle upon Tyne during 2012, the technique allows simulation of inundation for a 31km^2 of the city centre in less than an hour on a 2m grid; however, further grid refinement is required to fully capture important smaller flow pathways. Good agreement between the model and observed inundation is achieved for a variety of dam failure, slow fluvial inundation, rapid pluvial inundation, and defence breach scenarios in the UK.