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HYPERstreamHS: A Dual layer MPI continuous large-scale hydrological Model

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Large-scale hydrological modelling is often used to address impacts on water resources of climate change and water uses. Besides the large scale, these modeling effort is usually extended over long periods, particularly when the objective is to evaluate the impact of future climate scenarios, or requires complex inversion procedures. Therefore, these models are characterized by high computational demands both on memory allocation, due to the large amount of data that should be processed, and run time, because of the large number of forward simulations required by model calibration and uncertainty analyses. This implies that High Performance Computing (HPC) is attracting growing interest by the hydrological community.
A number of applications adopted parallelization standards such as Message Passing Interface (MPI) and Open Multi-Processing (openMP) in order to reduce the computational cost, or focused on GPU (Graphics Processing Unit) parallel computing. However, the unquestionably advantages of parallel computing is accompanied by some limitations: the speedup, i.e. the improvement in run time execution due to parallelization, stops increasing once the number of processors exceeds a certain threshold and the time spent in the point-to-point communication between processors becomes critical. This issue is particularly evident in hydrological models where streamflow routing along the river network has to be executed serially, thus not allowing full parallelization of the code, due to the presence of complex network of human infrastructures.
Driven by this motivation, in the present study we present the strategy adopted to parallelize a hydrological model based on the routing scheme named HYPERstream. In the parallelized version of this model, we coined HYPERstreamHS, we added modules dealing with the alterations introduced by water infrastructures, such as reservoirs and diversions. The model adopts a dual-layer parallelization strategy, based on the MPI standard, in order to fully exploit the parallelism in both computational time and memory allocation.
The first level of parallelization shares among the processors the simulation of the physical processes acting in each individual hydrological unit in which the watershed is partitioned. When the presence of a high number of hydraulic infrastructures in the hydrological conceptual model limits model scalability by increasing dramatically the point-to-point communication, a second layer is introduced. In particular, this second layer deals with model calibration and uncertainty analyses by subdividing the available processors in sub-sets, each one managing an independent simulation of the hydrological model adopting a given set of parameters.
The model scalability and efficiency have been tested on the Adige river basin, located in the south-eastern part of the Alps. In particular, regarding the first palletization level, results show that the hydrological model presents a scalability near to the theoretical one, up to 16 threats, while it scales rapidly to a sublinear behaviour with 32 and 64 threats. Furthermore, the test cases on the second palletization level showed that this strategy is able to restore mostly a linear speed-up.