ALPINE: A set of portable plasma physics particle-in-cell mini-apps for exascale

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Heterogeneous computing architectures are unavoidable moving towards the era of exascale computing. Computing nodes are being built with ever increasing depth of hierarchy. Hardware as well as performance portability are key capabilities to make efficient use of them. Particle-in-cell (PIC) methods are the method of choice in computational simulations of many physical applications including but not limited to particle accelerators, nuclear fusion and astrophysics. Hence, portability in the context of PIC schemes is the need of the hour to carry out these extreme scale simulations in current and next generation architectures.

Alpine consists of a set of mini-apps which provide a test bed for implementing new algorithms and/or novel implementations of existing algorithms related to PIC schemes in the context of exascale architectures in a portable way. Alpine is based on IPPL (Independent Parallel Particle Layer) a framework that is designed around performance portable and dimension independent particles and fields.

We consider the following mini-apps which are most commonly used in electrostatic PIC studies: linear and non-linear Landau damping, bump-on-tail or two-stream instability and a Penning trap. The mentioned mini-apps are benchmarked with varying grid sizes (512^3-2048^3) and number of simulation particles (10^9-10^{11}). We show strong and weak scaling and analyse the performance of different components on several pre-exascale architectures such as Piz-Daint, Cori, Perlmutter and Summit up to thousands of CPU cores and GPUs.

The performance study in this work provides important insights on different components of PIC schemes in different architectures This work will serve as a guidance for the plasma PIC community to identify the major reasons for performance limitations, and better prepare for exascale architectures. So far portable, exascale PIC studies are mostly in the context of electromagnetic PIC schemes. To the best of our knowledge this is the first study which considers the performance of electrostatic PIC in such context