Using AmgX to accelerate a PETSc-based Immersed Boundary Method code

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Abstract

We develop an open-source `PETSc`-based immersed boundary method code using a fully discrete projection formulation. We accelerate the time to solution using the Nvidia-library `AmgX` on multi CUDA-capable GPU devices. We aim to use our code to study the three-dimensional flow around a flying-snake to reveal lift-enhancement mechanisms used by this unconventional glider.

Keywords: Immersed Boundary Method, `PETSc`, `AmgX`, flying snake

1. PetIBM and AmgXWrapper

We have developed `PetIBM`[1] that implements using the `PETSc`[2] library, an immersed-boundary method (IBM) [1] in which the fully discrete algebraic system is solved via a projection method based on an approximate block-LU decomposition. The data structures and routines provided by the `PETSc` library allowed us to rapidly develop a software that runs on distributed-memory architectures.

As expected with the projection method, the iterative Poisson solver is the bottleneck in our simulations. This is even worse for the IBM we use where the modified Poisson operator becomes larger and possesses more off-diagonal

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[1] `PetIBM`: https://github.com/barbagroup/PetIBM

[2] `PETSc`: https://www.mcs.anl.gov/petsc

entries. To overcome this challenge, we use the Nvidia-library `AmgX`[3] to solve the iterative system on multiple CUDA-capable GPU devices. We have developed an `AmgX` wrapper[4] that provides the interface with the PETSc library and incorporated it in `PetIBM`. Past two-dimensional simulations with `PetIBM` showed a 21 times application speed-up in runtime when using our `AmgX` wrapper on one GPU node compared to using `PETsc` on a CPU node (see Figure 1).

The full codes, `PetIBM` and `AmgXWrapper`, are open-source, released under MIT license, and version-controlled on GitHub.

2. Flying snakes to the cloud

We aim to study the aerodynamics of the *Chrysopelea paradisi*, a species of snake with the amazing capability to glide through the air. Previous experimental work [2] and two-dimensional simulations [3] reported enhanced lift force on a snake gliding at a particular angle of attack of 35^o. Using `PetIBM` and `AmgXWrapper`, we now intend to understand the three-dimensional wake structures responsible for high gliding performances of the paradise tree snake.

Finally, we decided to use the public cloud Microsoft Azure to run our simulations so that we could compare the performances with our University HPC cluster.

References

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[2] D. Holden, J. J. Socha, N. D. Cardwell, P. P. Vlachos, Aerodynamics of the flying snake chrysopelea paradisi: how a bluff body cross-sectional shape contributes to gliding performance, Journal of Experimental Biology 217 (3) (2014) 382–394.

[3] `AmgX`: https://developer.nvidia.com/amgx
[4] `AmgXWrapper`: https://github.com/barbagroup/AmgXWrapper

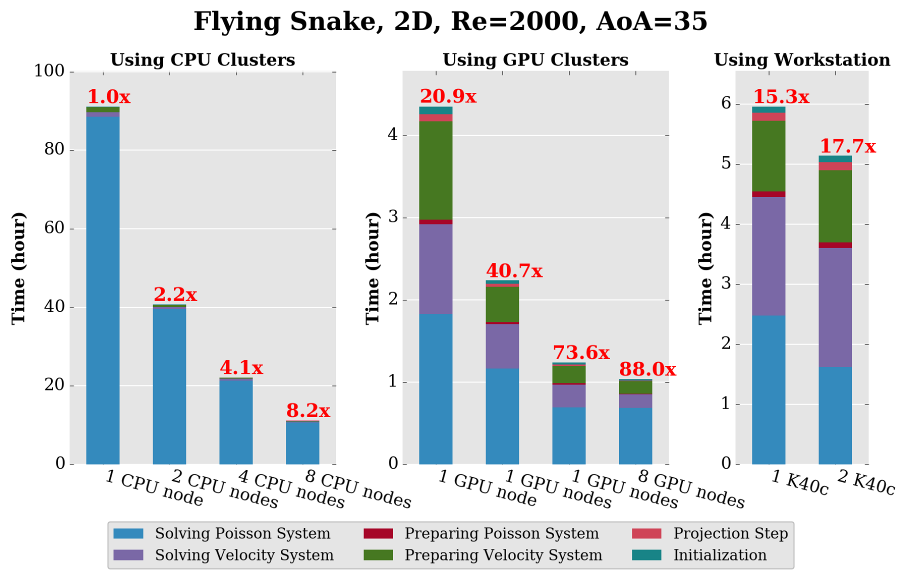

Figure 1: Runtimes for the flying-snake case, using `PetIBM` and `AmgX`.

[3] A. Krishnan, J. J. Socha, P. P. Vlachos, L. Barba, Lift and wakes of flying snakes, Physics of Fluids 26 (3) (2014) 031901.