Overlapping Computation and Communication for Advection on Hybrid Parallel Computers

James B White III (Trey)
trey@ucar.edu
National Center for Atmospheric Research

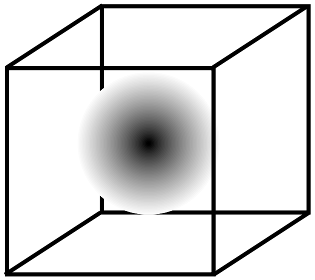
Jack Dongarra
dongarra@eecs.utk.edu
University of Tennessee, Knoxville

Programming Weather, Climate, and Earth-System Models
on Heterogeneous Multi-Core Platforms
NCAR, September 8, 2011

based on work first presented at IPDPS, Anchorage, AK, May 17, 2011

Portions of this work were funded by the Office of Biological and Environmental Research and the Office of Advanced Scientific Computing Research, both of the US Department of Energy. This research used resources of the OLCF at Oak Ridge National Laboratory and of NERSC at Lawrence Berkeley National Laboratory, both of which are supported by the Office of Science of the US Department of Energy.

Test Case



- Linear advection with constant uniform velocity
- Three-dimensional cube with periodic boundaries
- Advect Gaussian wave through cube corner back to original position
- Strong scaling, 420x420x420
- Explicit 2nd-order single-stage integration, 3x3x3 centered stencil, 64-bit precision

Computers

System	JaguarPF	Hopper II	Lens	Yona
Compute nodes	18688	6392	31	16
Memory per node (GB)	16	32	64	32
AMD Opteron sockets per node	2	2	4	2
Cores per Opteron socket	6	12	4	6
Opteron clock (GHz)	2.6	2.1	2.3	2.6
Interconnect	Cray SeaStar 2+	Cray Gemini	DDR Infiniband	QDR Infiniband
MPI	Cray MPT 4.0.0	Cray MPT 5.1.3	OpenMPI 1.3.3	OpenMPI 1.7a1
NVIDIA Tesla GPU	–	–	C1060	C2050
GPU memory (GB)	–	–	4	3

Computers

System	JaguarPF	Hopper II	Lens	Yona
Compute nodes	18688	6392	31	16
Memory per node (GB)	16	32	64	32
AMD Opteron sockets per node	2	2	4	2
Cores per Opteron socket	6	12	4	6
Opteron clock (GHz)	2.6	2.1	2.3	2.6
Interconnect	Cray SeaStar 2+	Cray Gemini	DDR Infiniband	QDR Infiniband
MPI	Cray MPT 4.0.0	Cray MPT 5.1.3	OpenMPI 1.3.3	OpenMPI 1.7a1
NVIDIA Tesla GPU	–	–	C1060	C2050
GPU memory (GB)	–	–	4	3

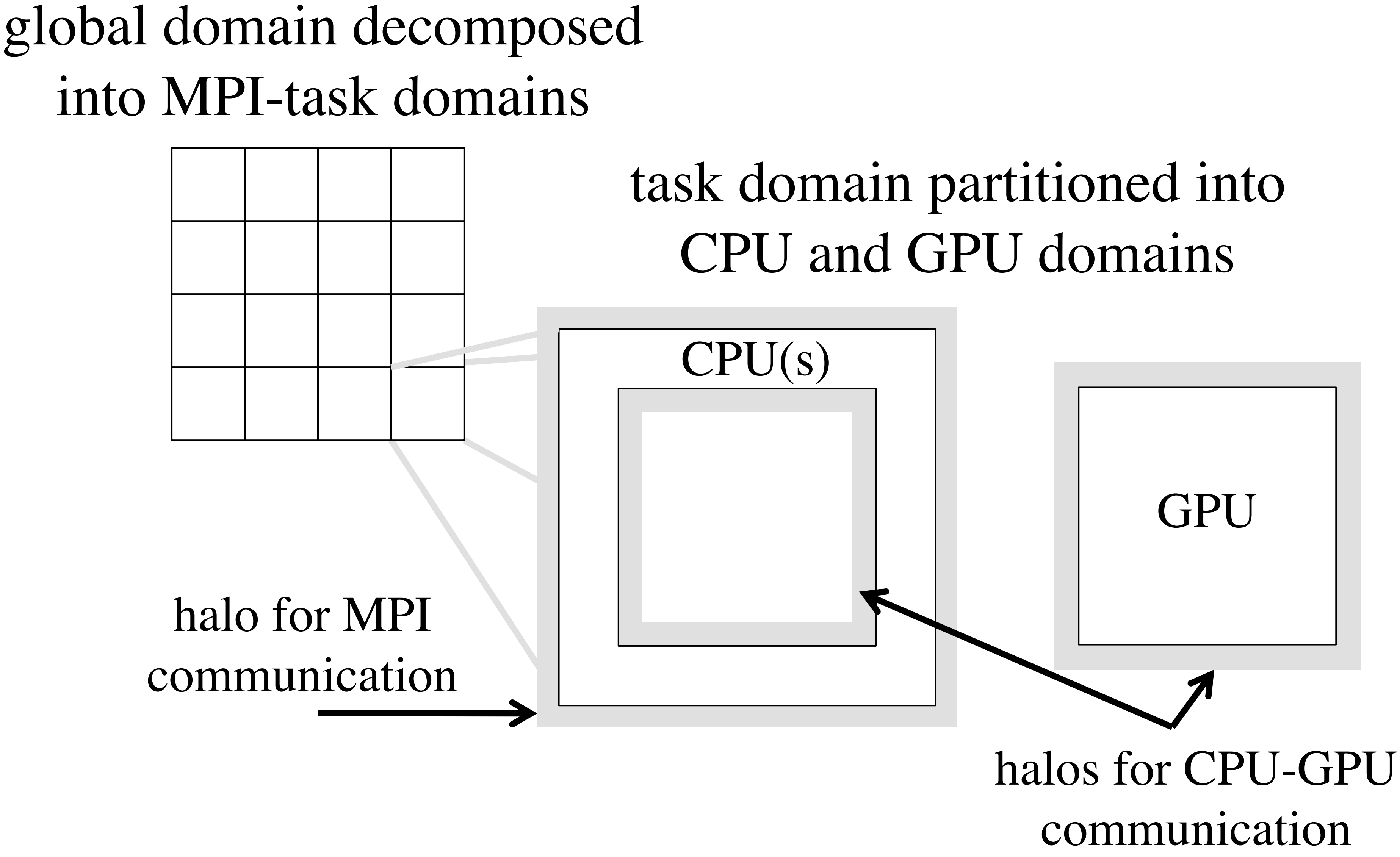
Computers

System	JaguarPF	Hopper II	Lens	Yona
Compute nodes	18688	6392	31	16
Memory per node (GB)	16	32	64	32
AMD Opteron sockets per node	2	2	4	2
Cores per Opteron socket	6	12	4	6
Opteron clock (GHz)	2.6	2.1	2.3	2.6
Interconnect	Cray SeaStar 2+	Cray Gemini	DDR Infiniband	QDR Infiniband
MPI	Cray MPT 4.0.0	Cray MPT 5.1.3	OpenMPI 1.3.3	OpenMPI 1.7a1
NVIDIA Tesla GPU	–	–	C1060	C2050
GPU memory (GB)	–	–	4	3

Implementations

- Single task (Fortran + OpenMP)
- Bulk-synchronous MPI
- MPI using nonblocking communication for overlap
- MPI using OpenMP threading for overlap
- GPU resident (CUDA Fortran)
- GPU with bulk-synchronous MPI
- GPU with MPI overlap using CUDA streams
- CPU and GPU computation with bulk-synchronous MPI
- CPU and GPU computation partitioned for overlap with nonblocking MPI and CPU-GPU communication

CPU-GPU Domain Decomposition



global domain decomposed into MPI-task domains

task domain partitioned into CPU and GPU domains

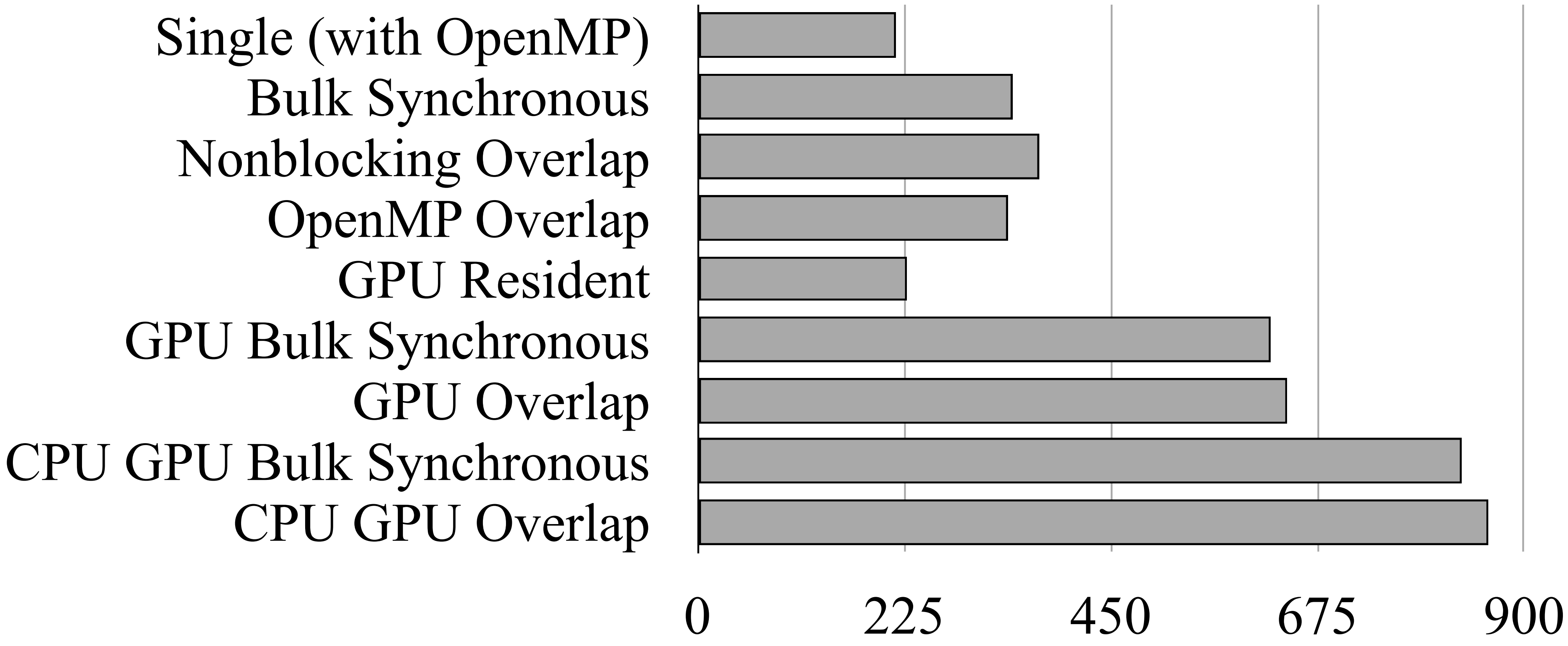
CPU(s)

GPU

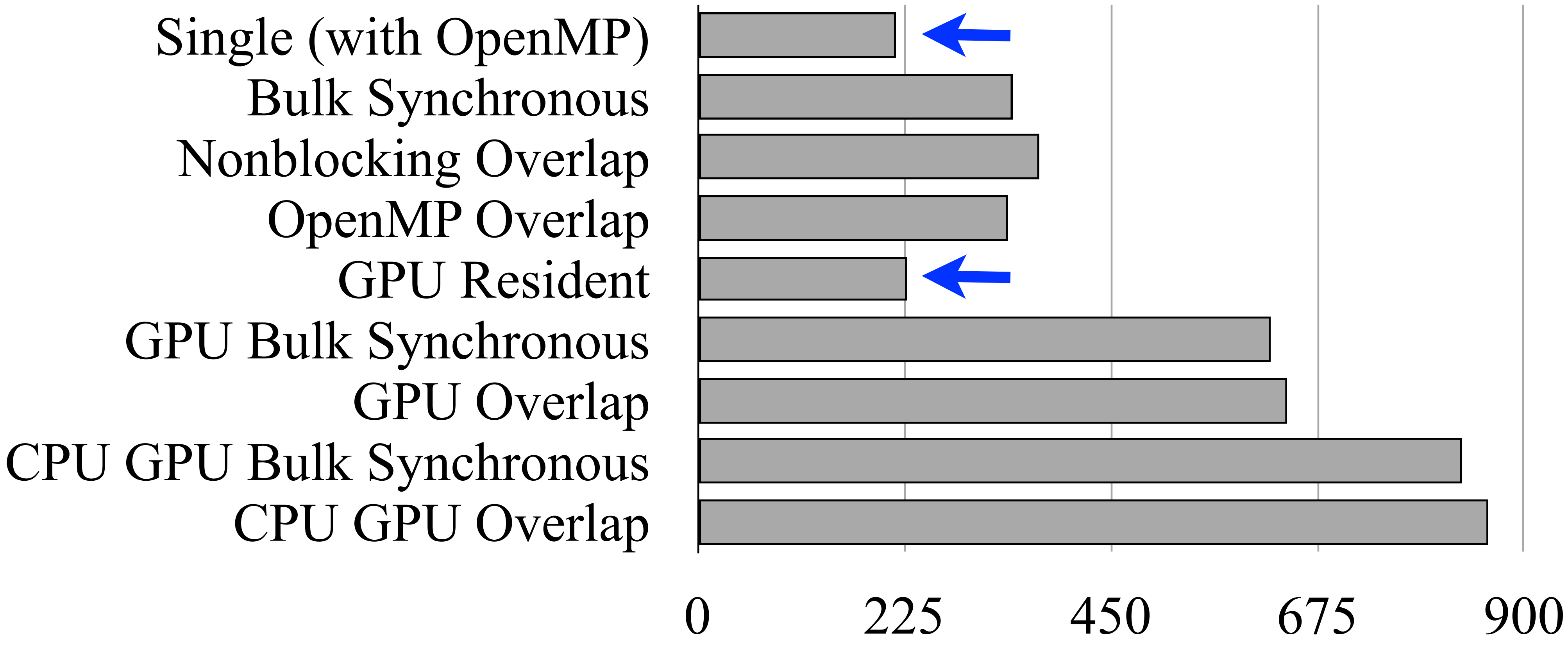
halo for MPI communication

halos for CPU-GPU communication

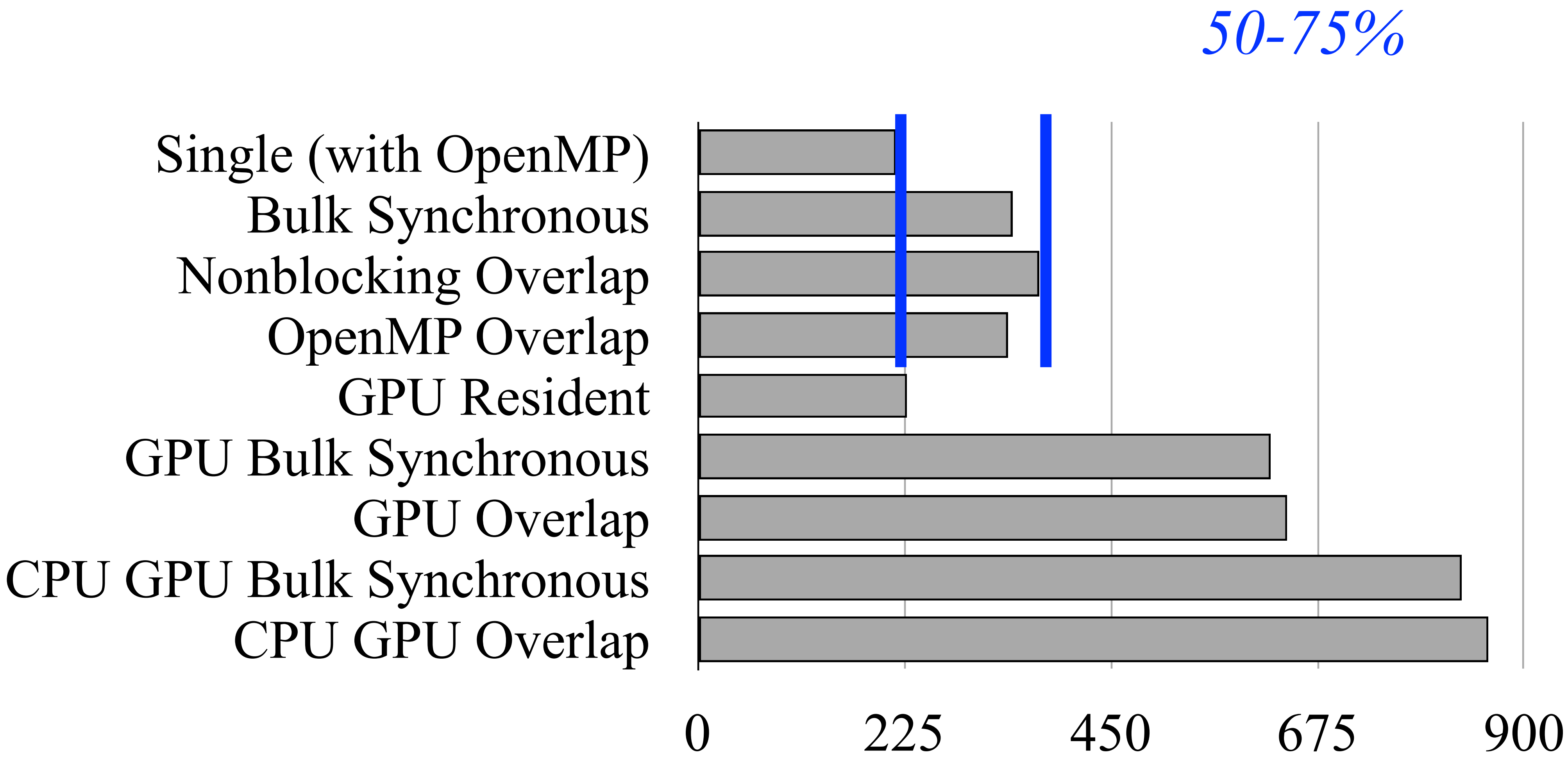
Lines of Code



Lines of Code

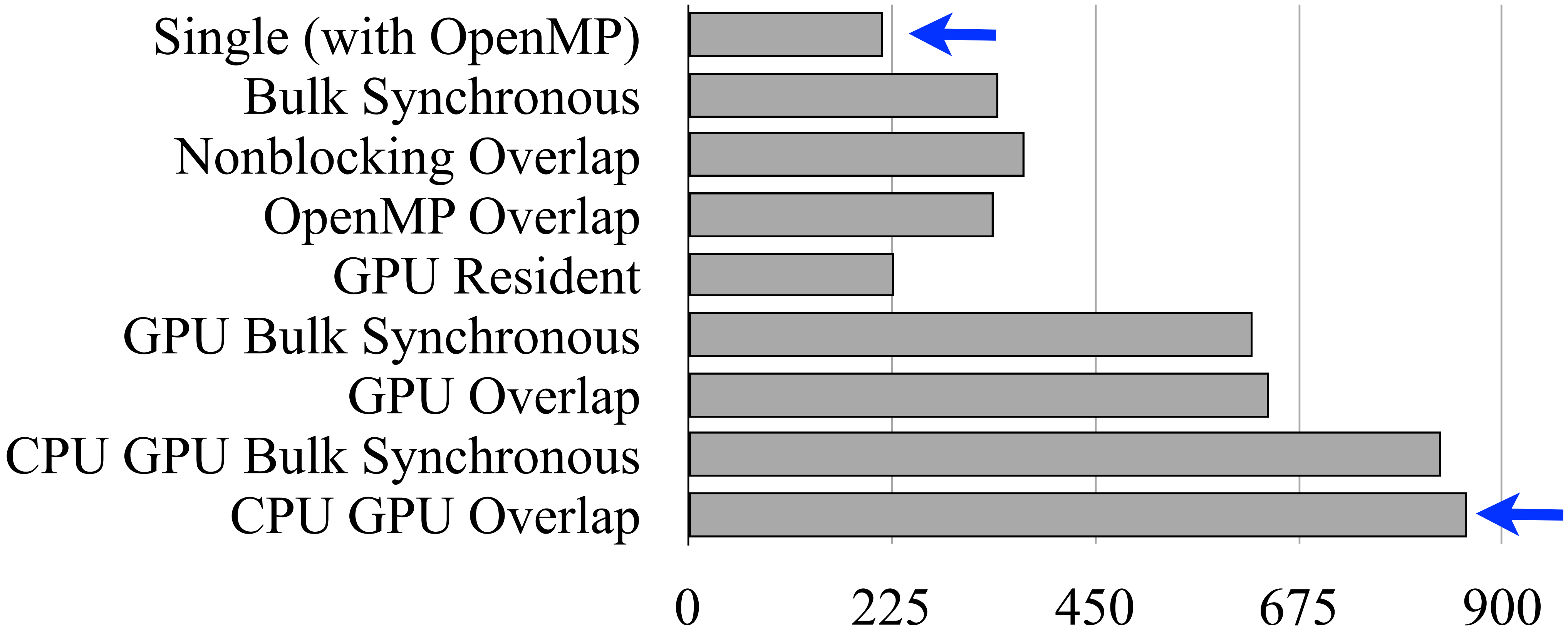


Lines of Code

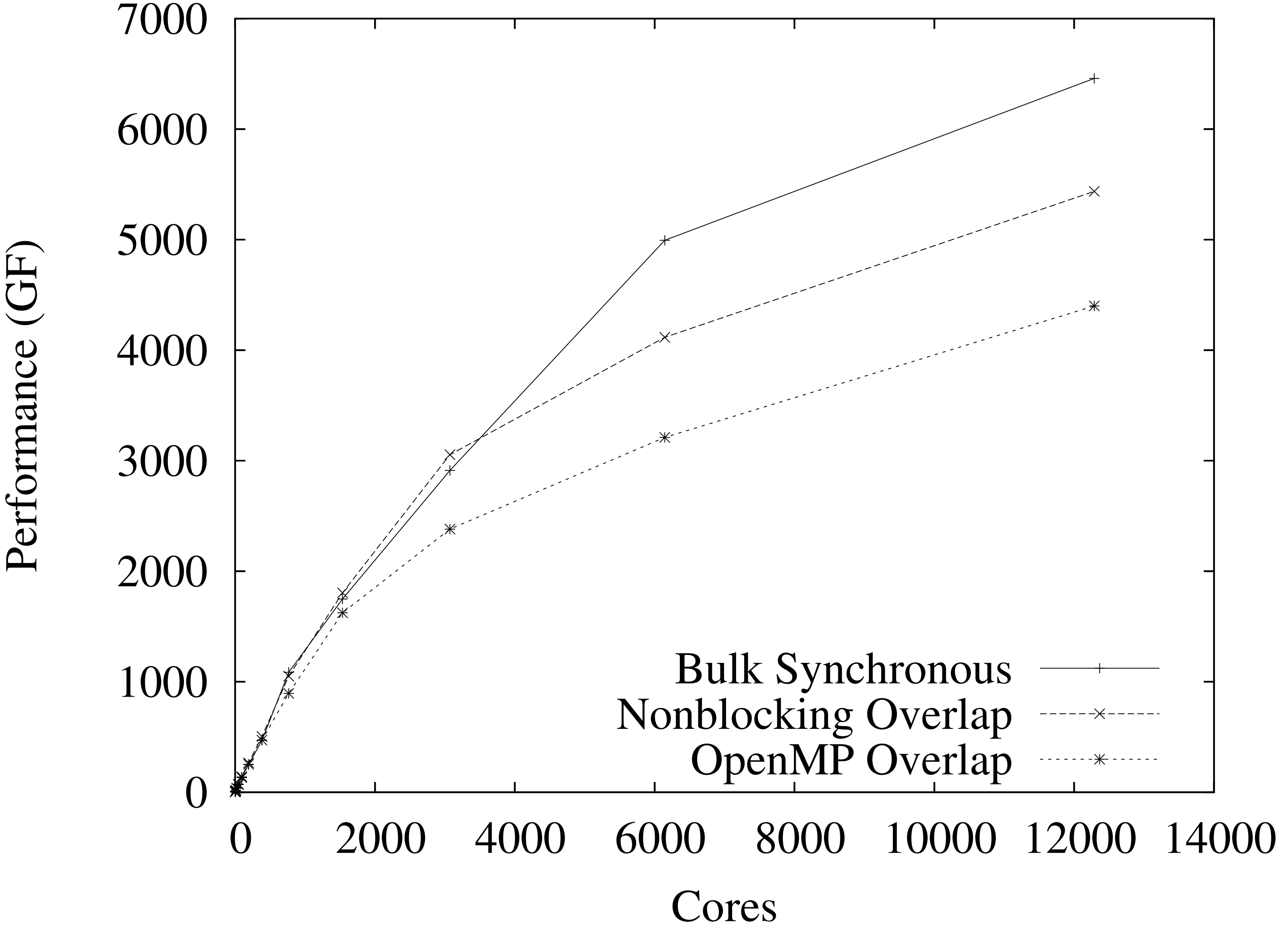


Lines of Code

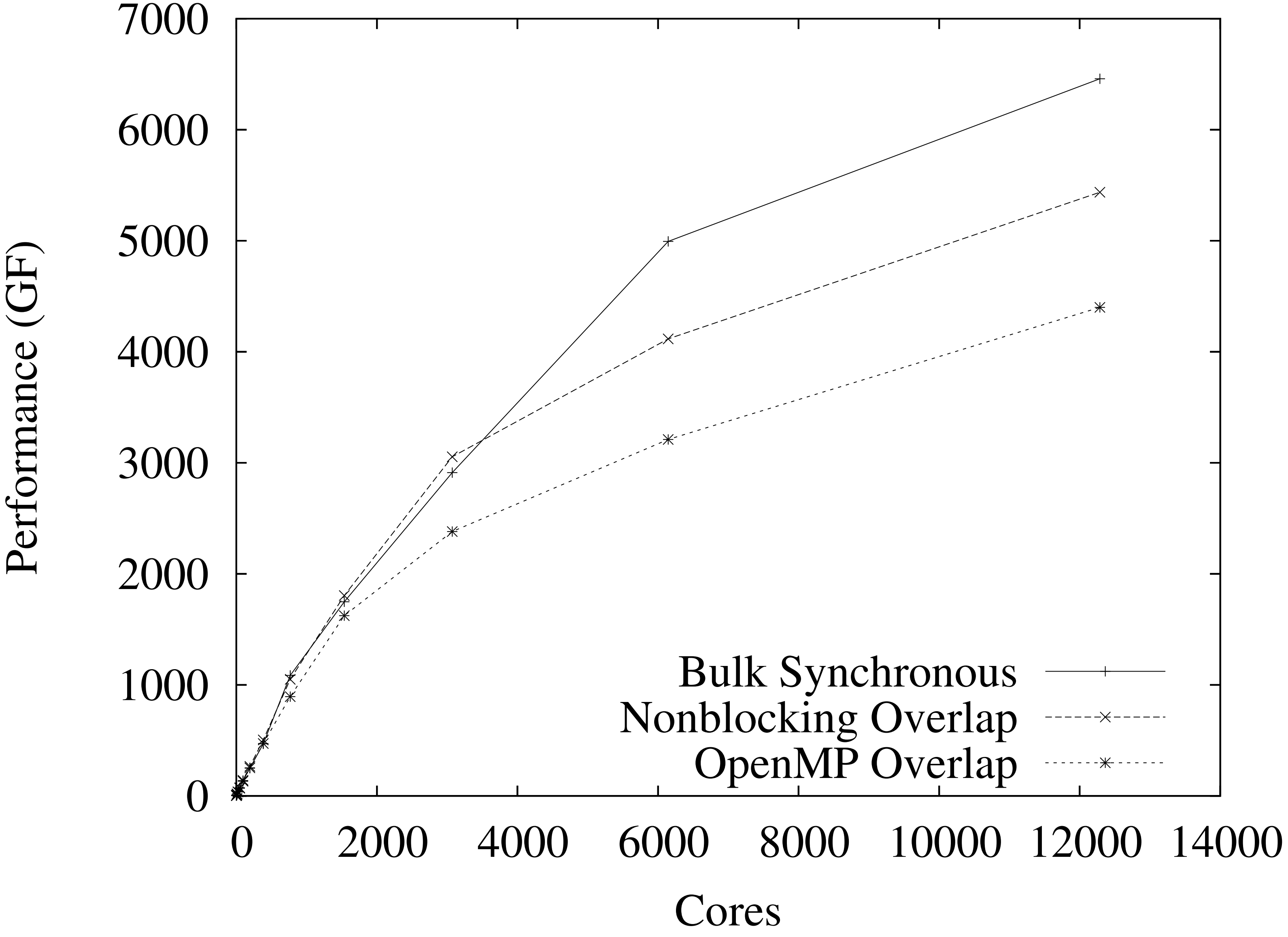
4



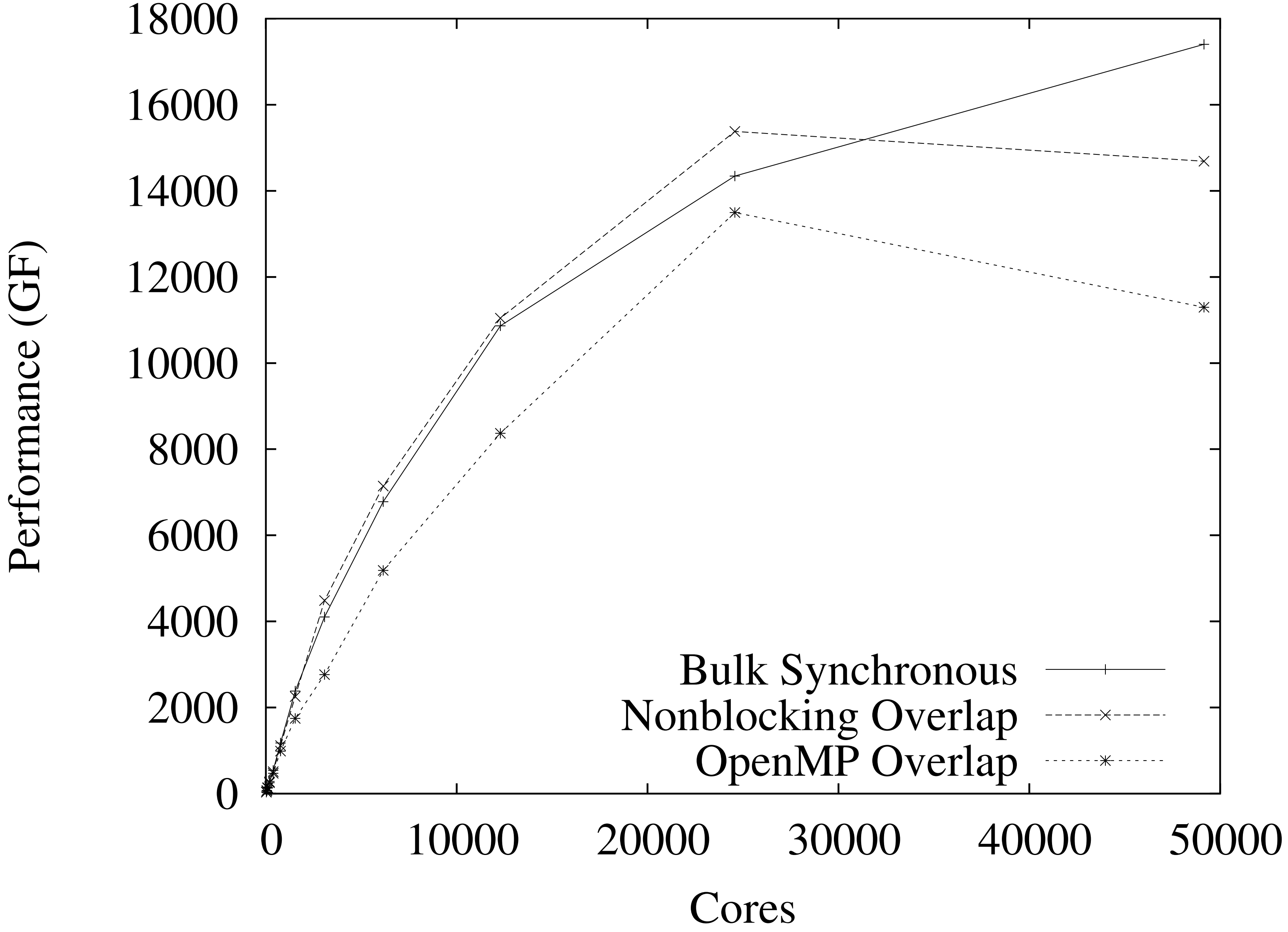
Best JaguarPF Performance



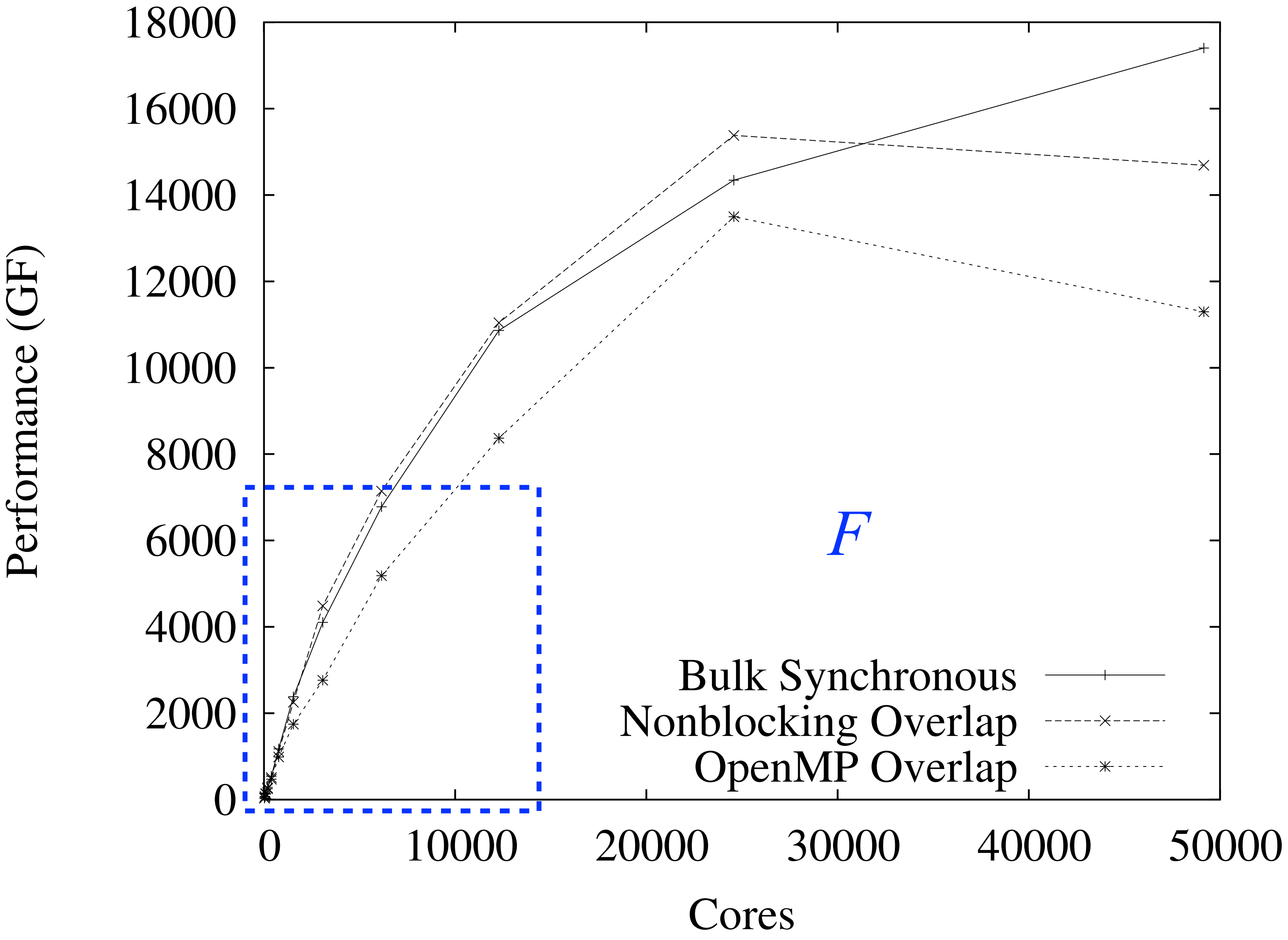
Best JaguarPF Performance



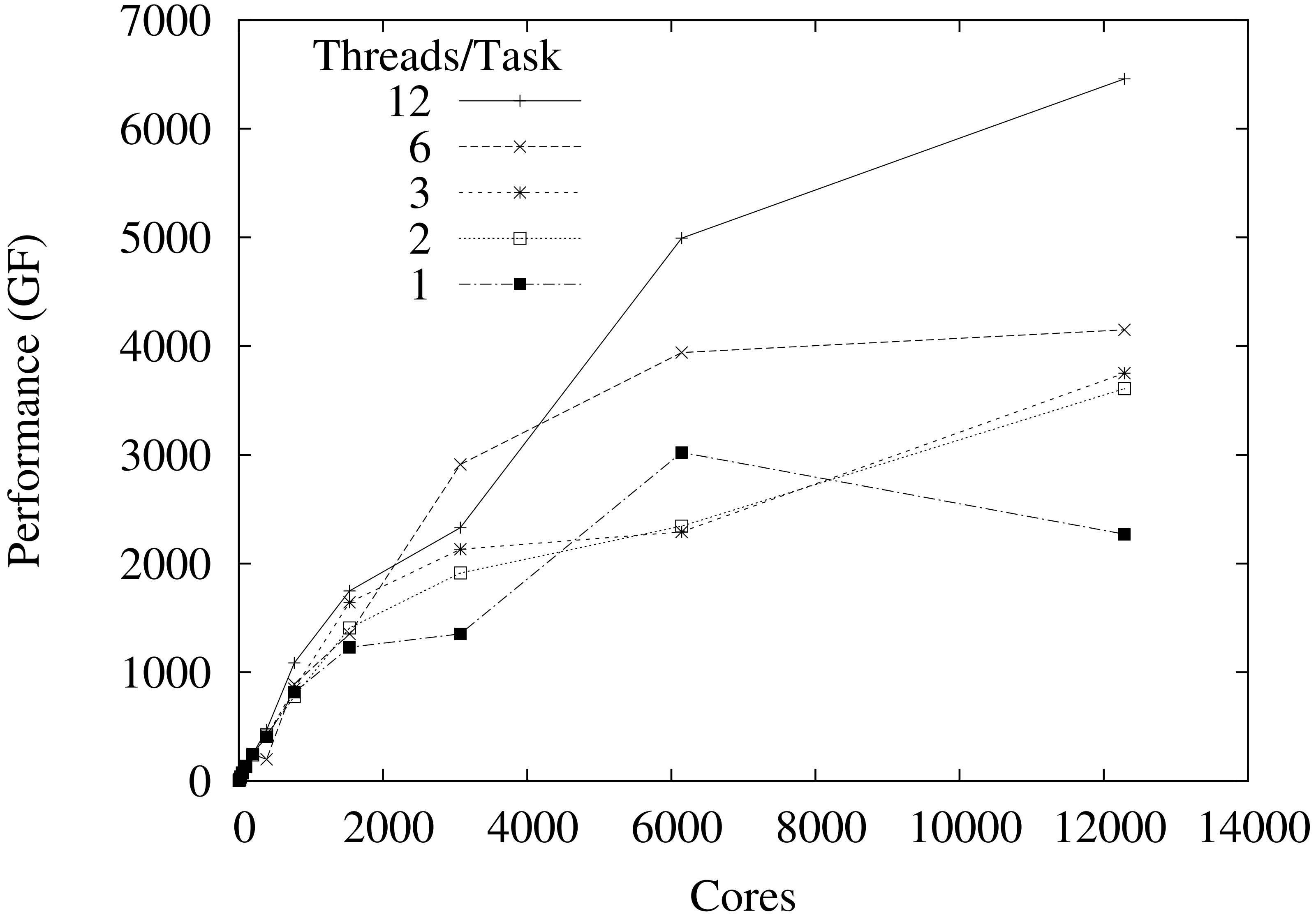
Best Hopper-II Performance



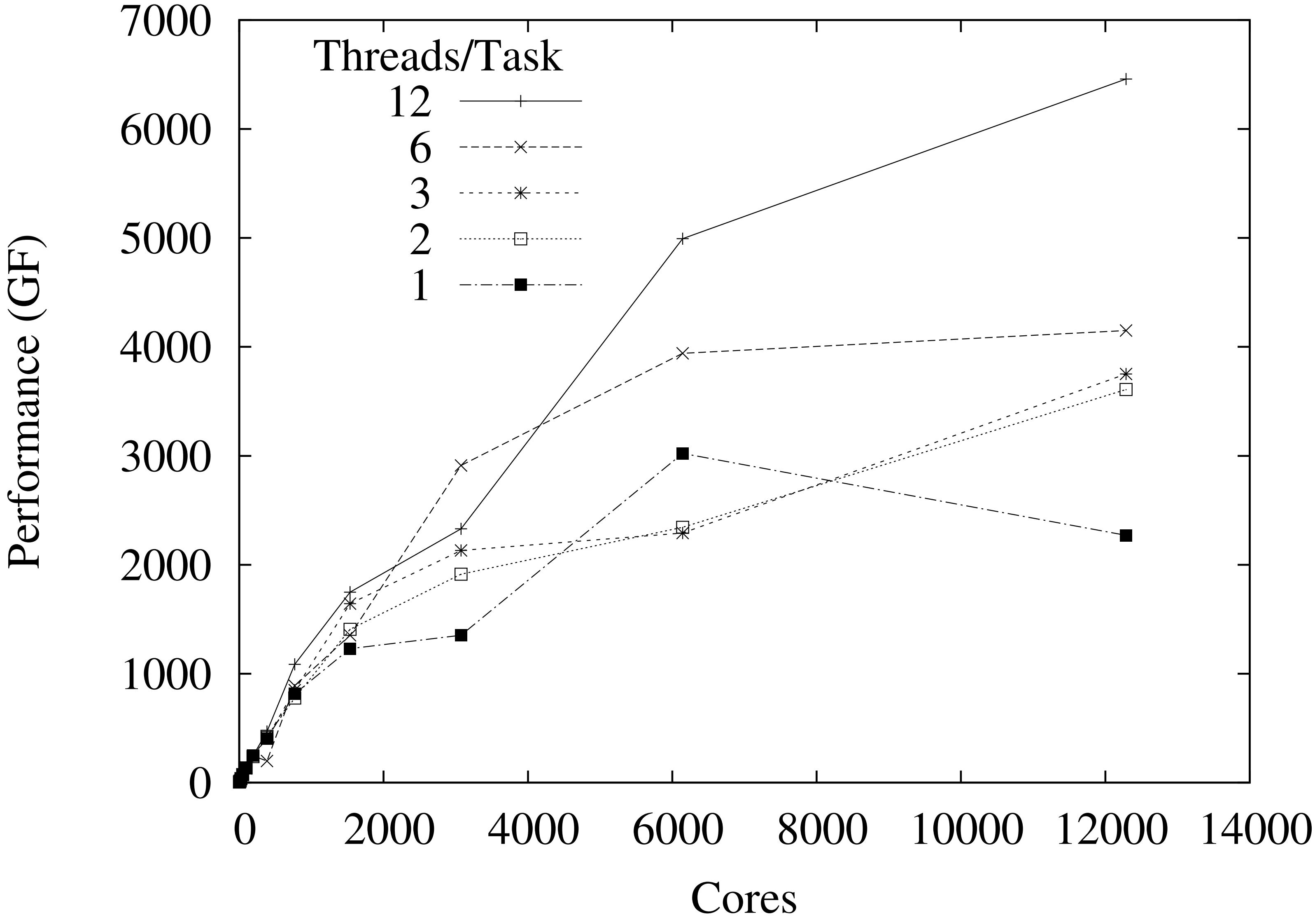
Best Hopper-II Performance



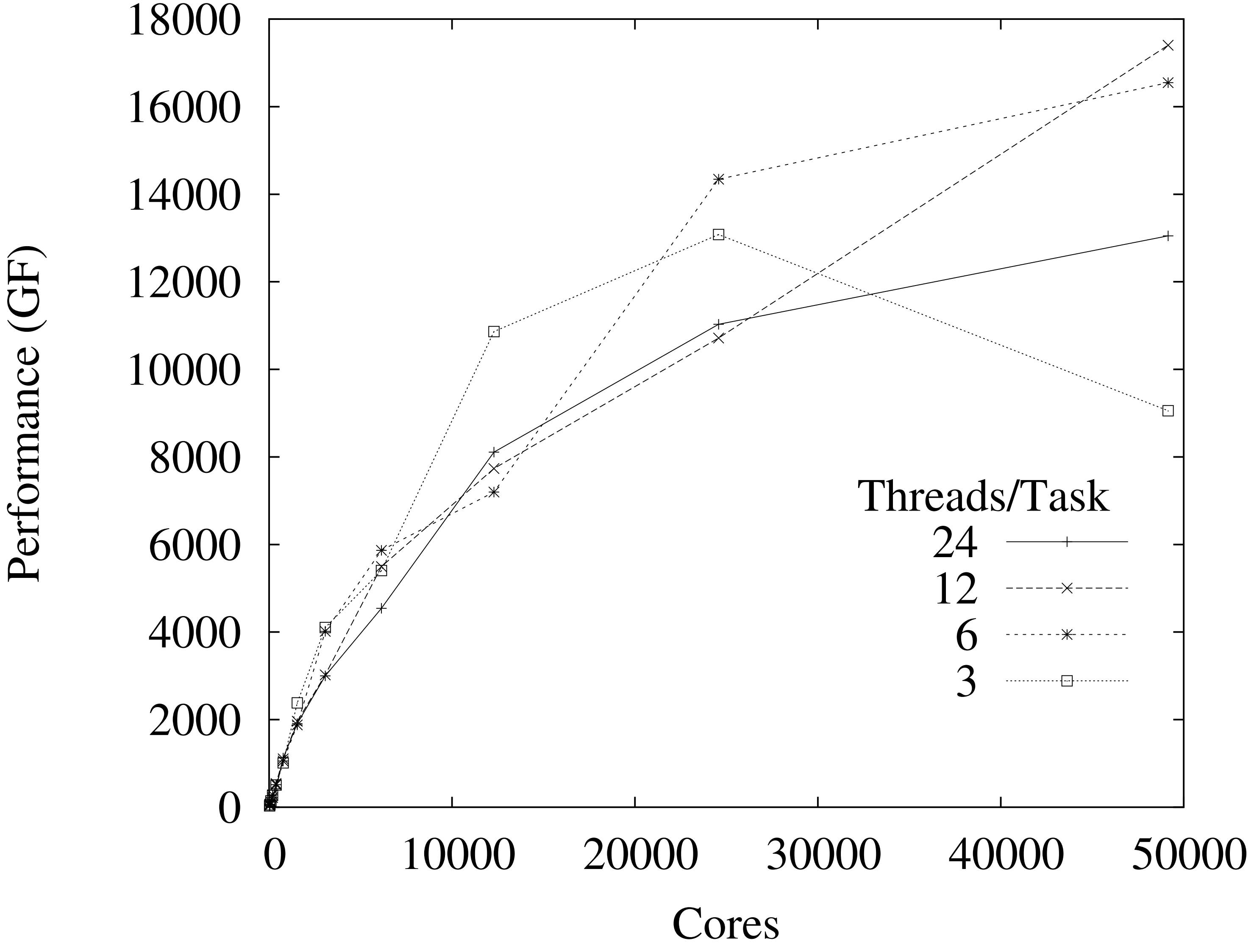
Bulk-Synchronous Performance on JaguarPF



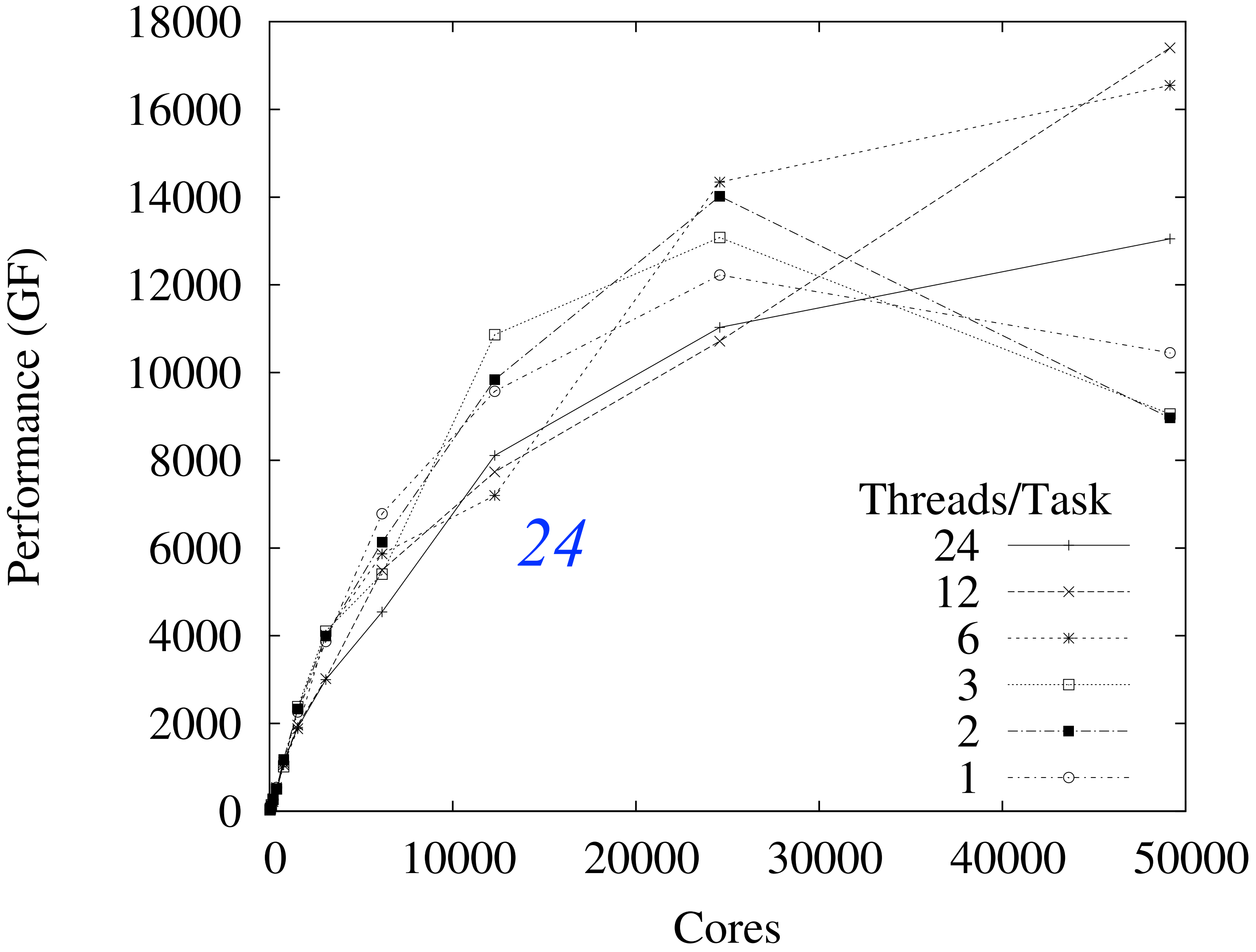
Bulk-Synchronous Performance on JaguarPF



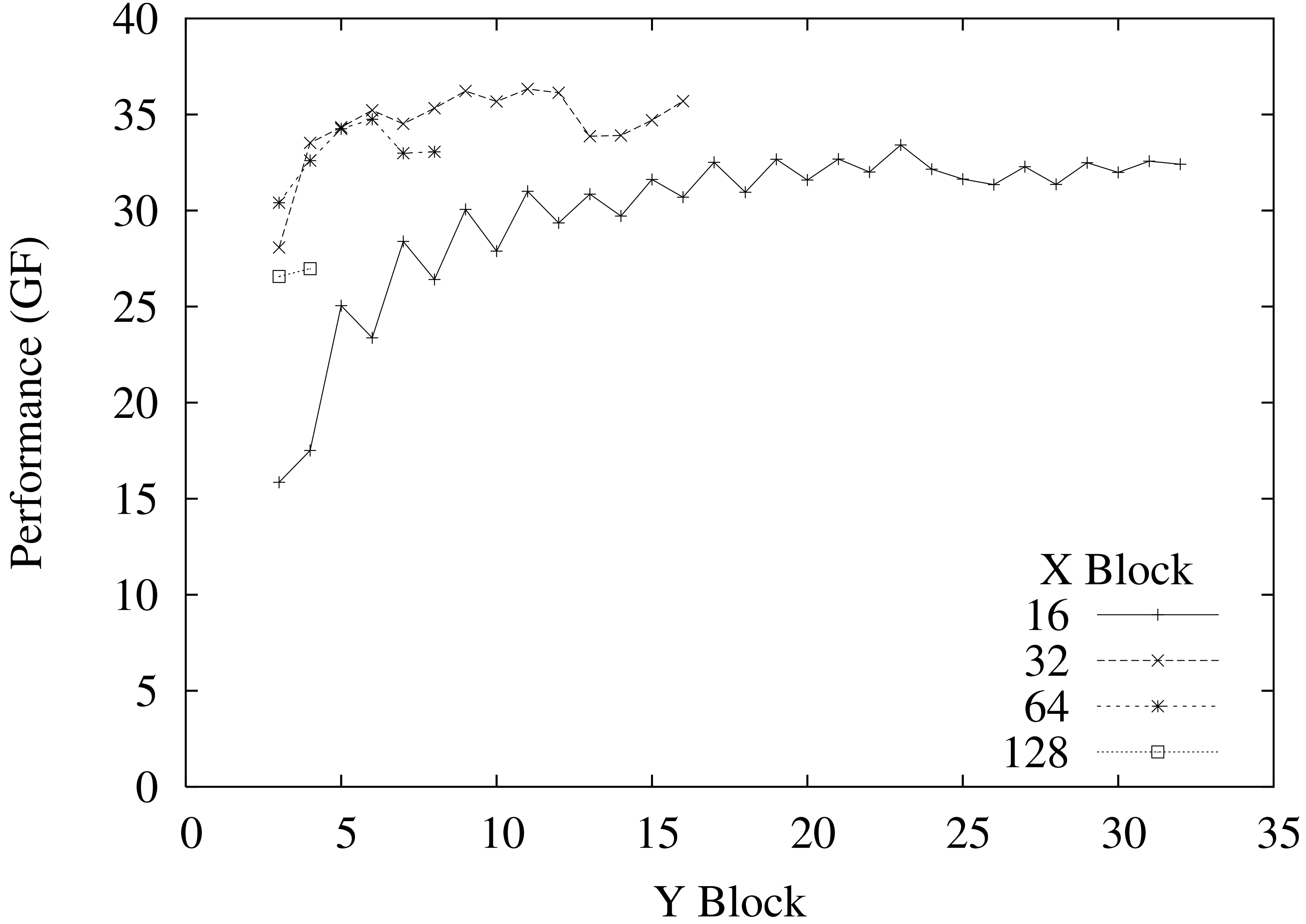
Bulk-Synchronous Performance on Hopper II



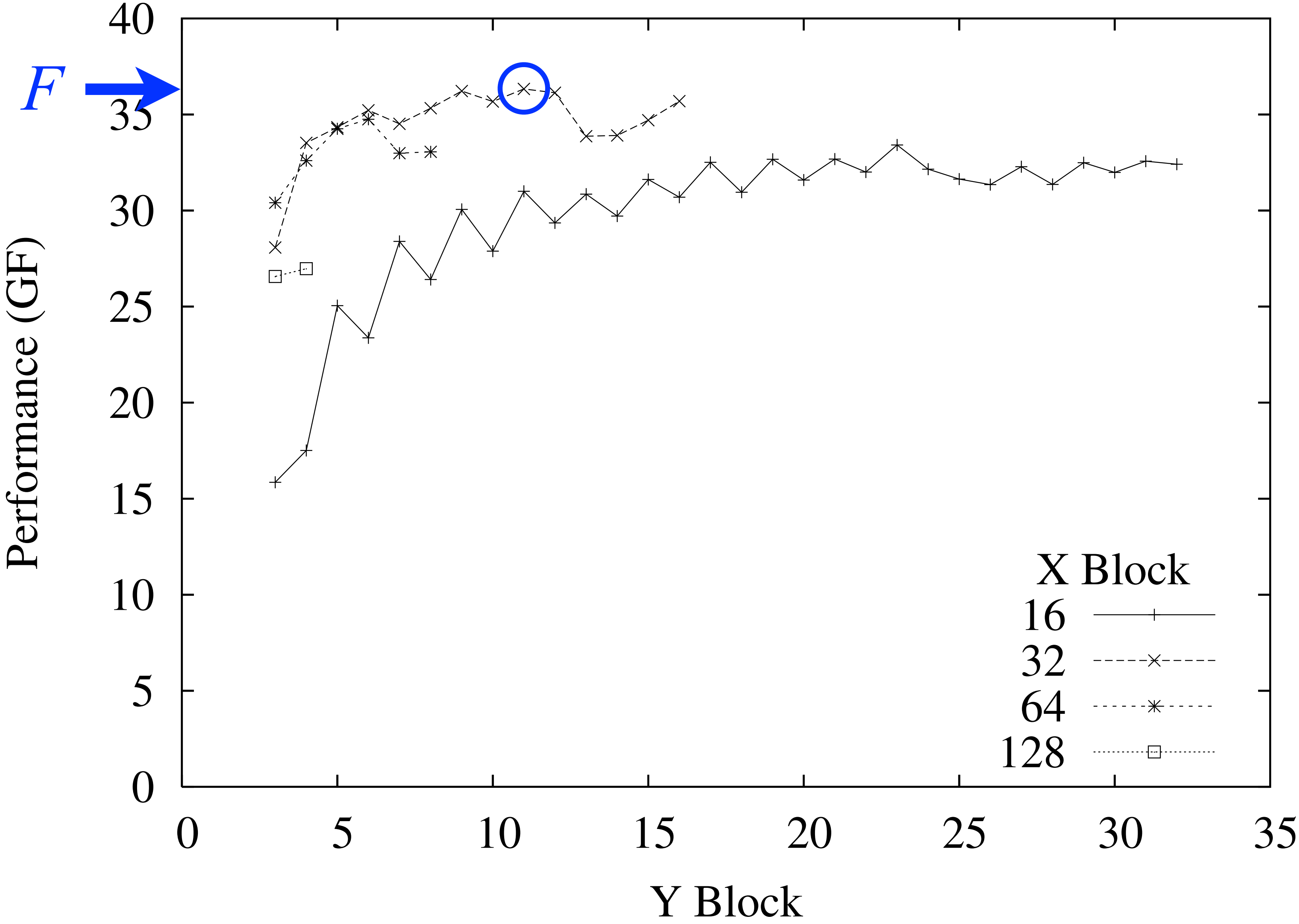
Bulk-Synchronous Performance on Hopper II



GPU-Resident Performance on Lens



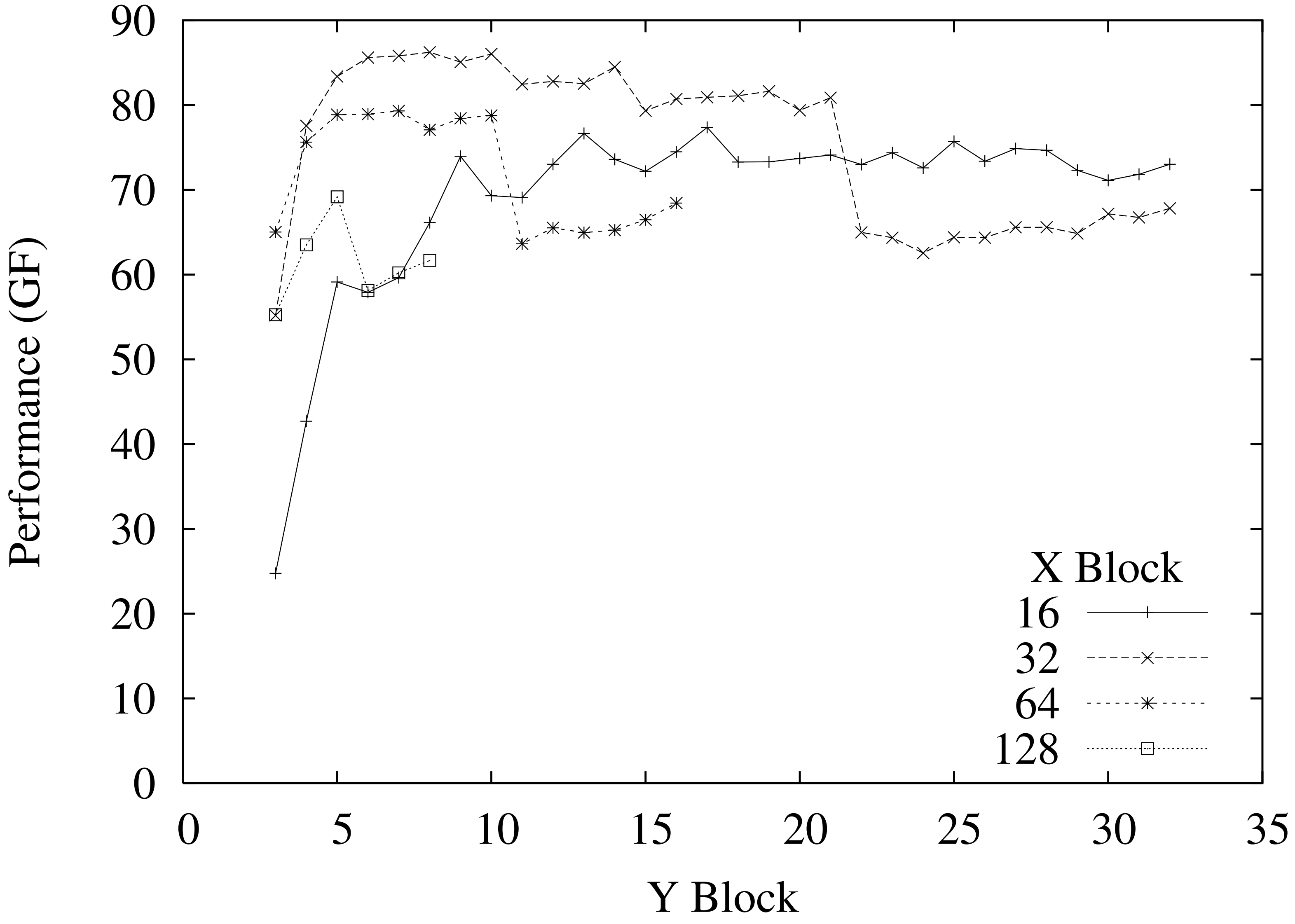
GPU-Resident Performance on Lens



32 11

36.3 F

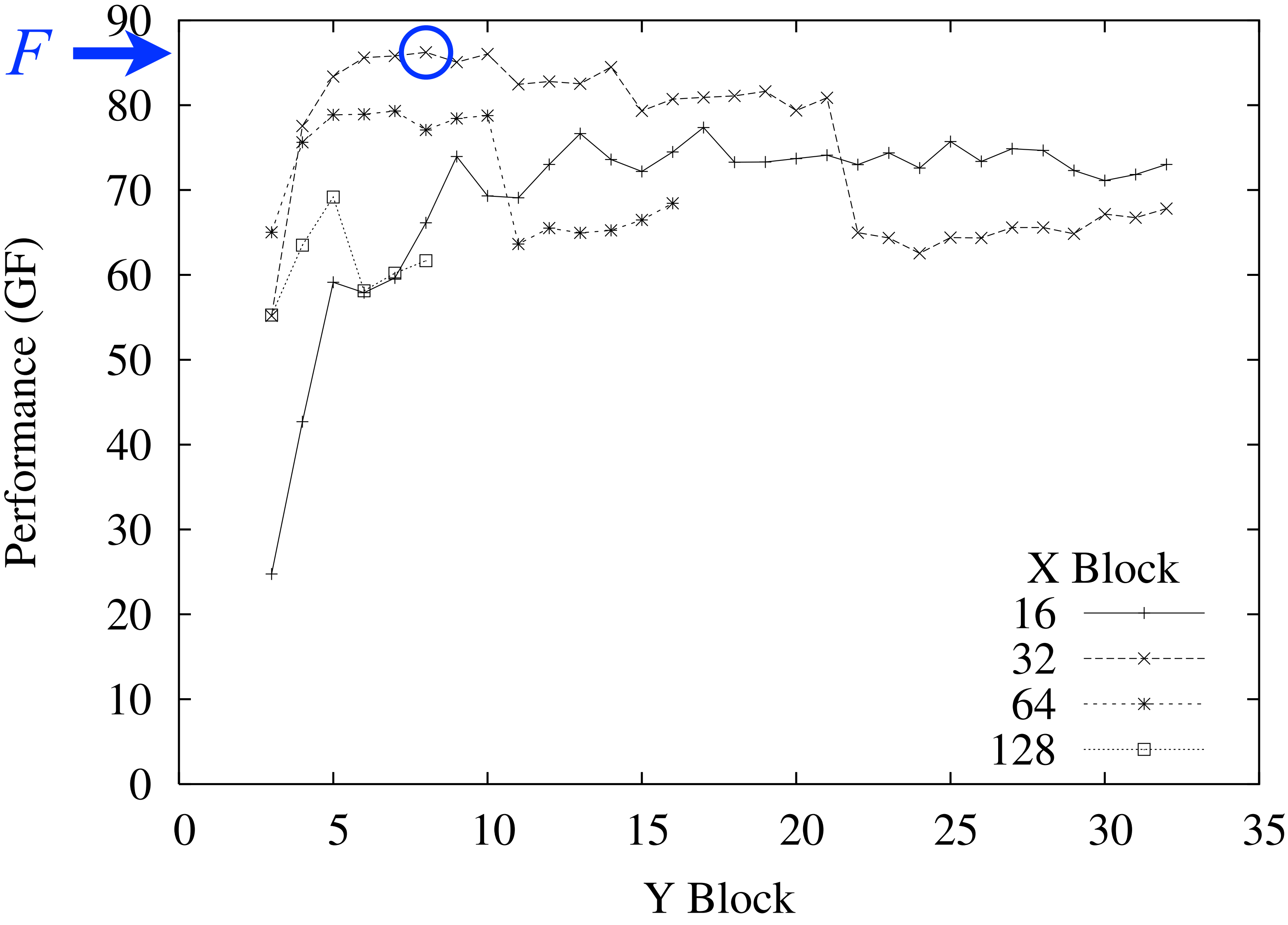
GPU-Resident Performance on Yona



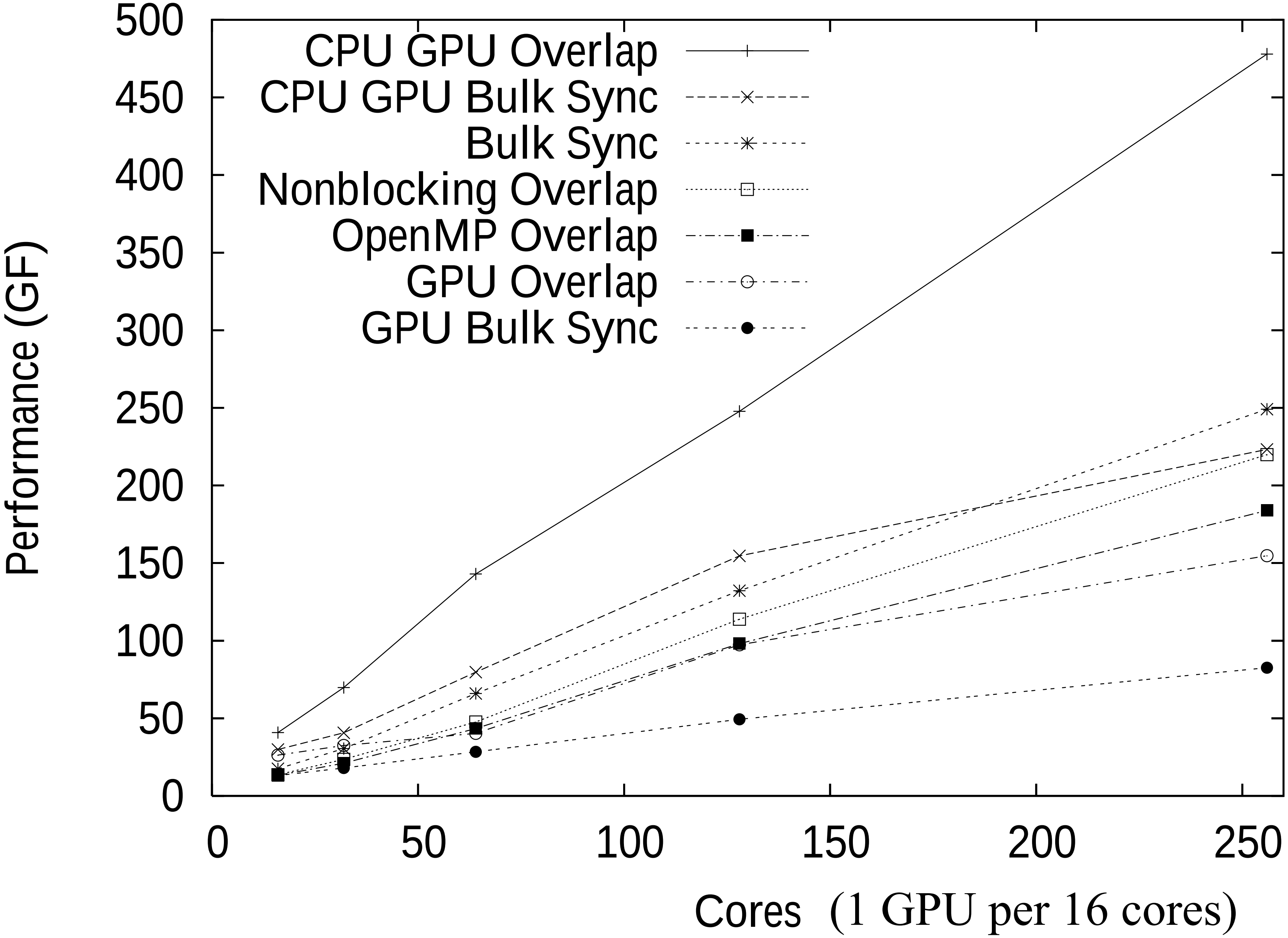
GPU-Resident Performance on Yona

32 8

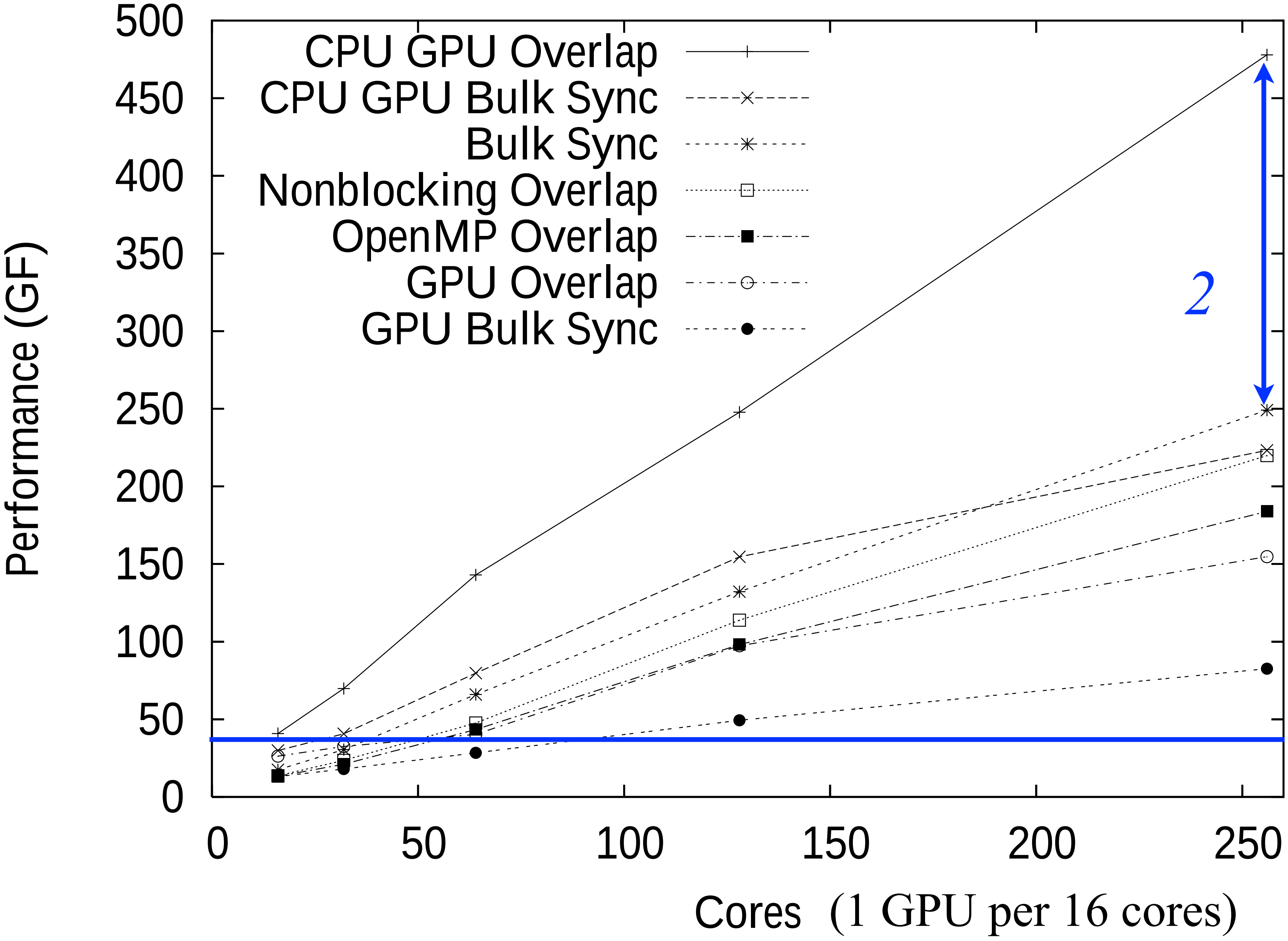
86.2 F



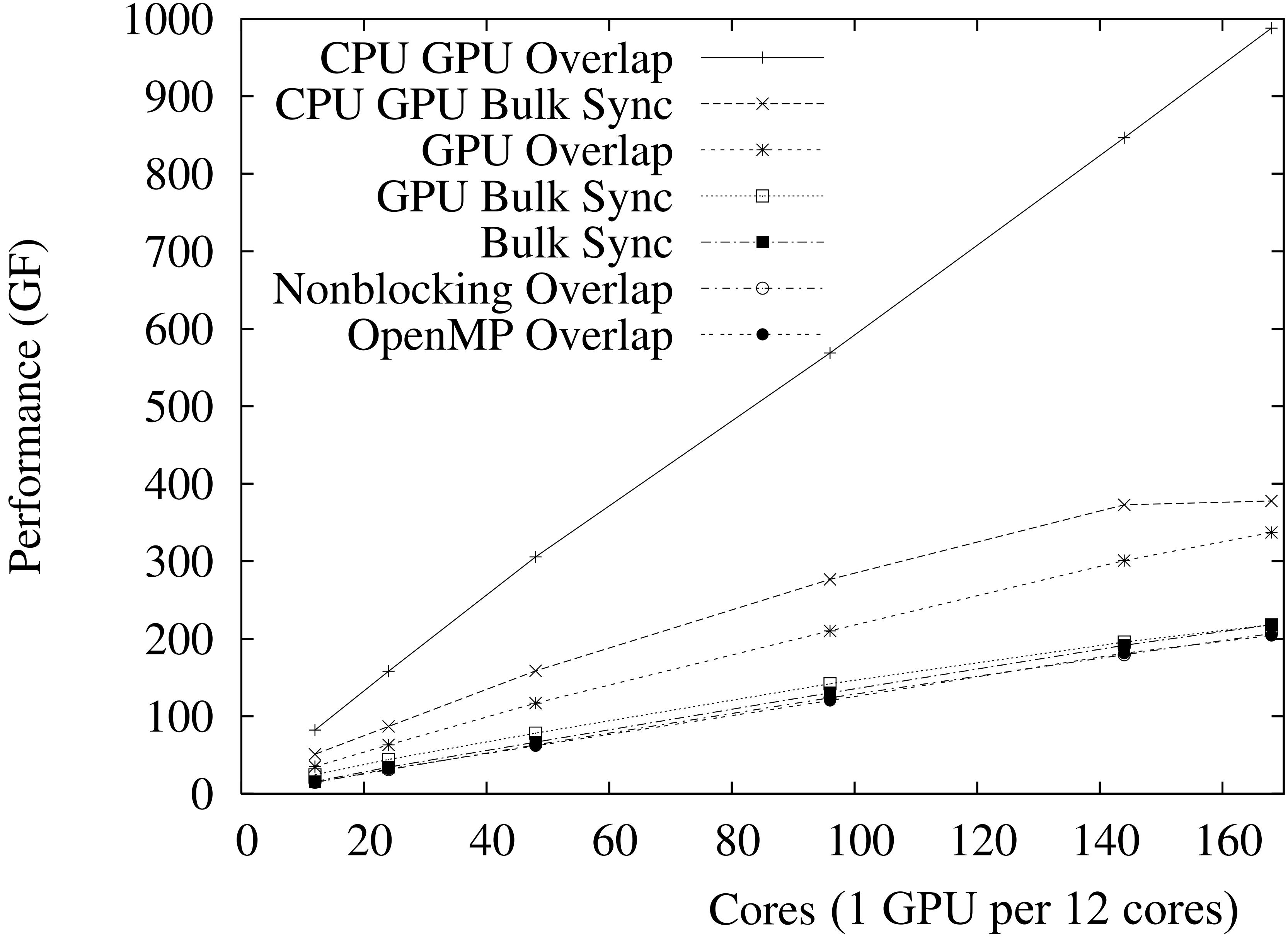
Best Performance on Lens



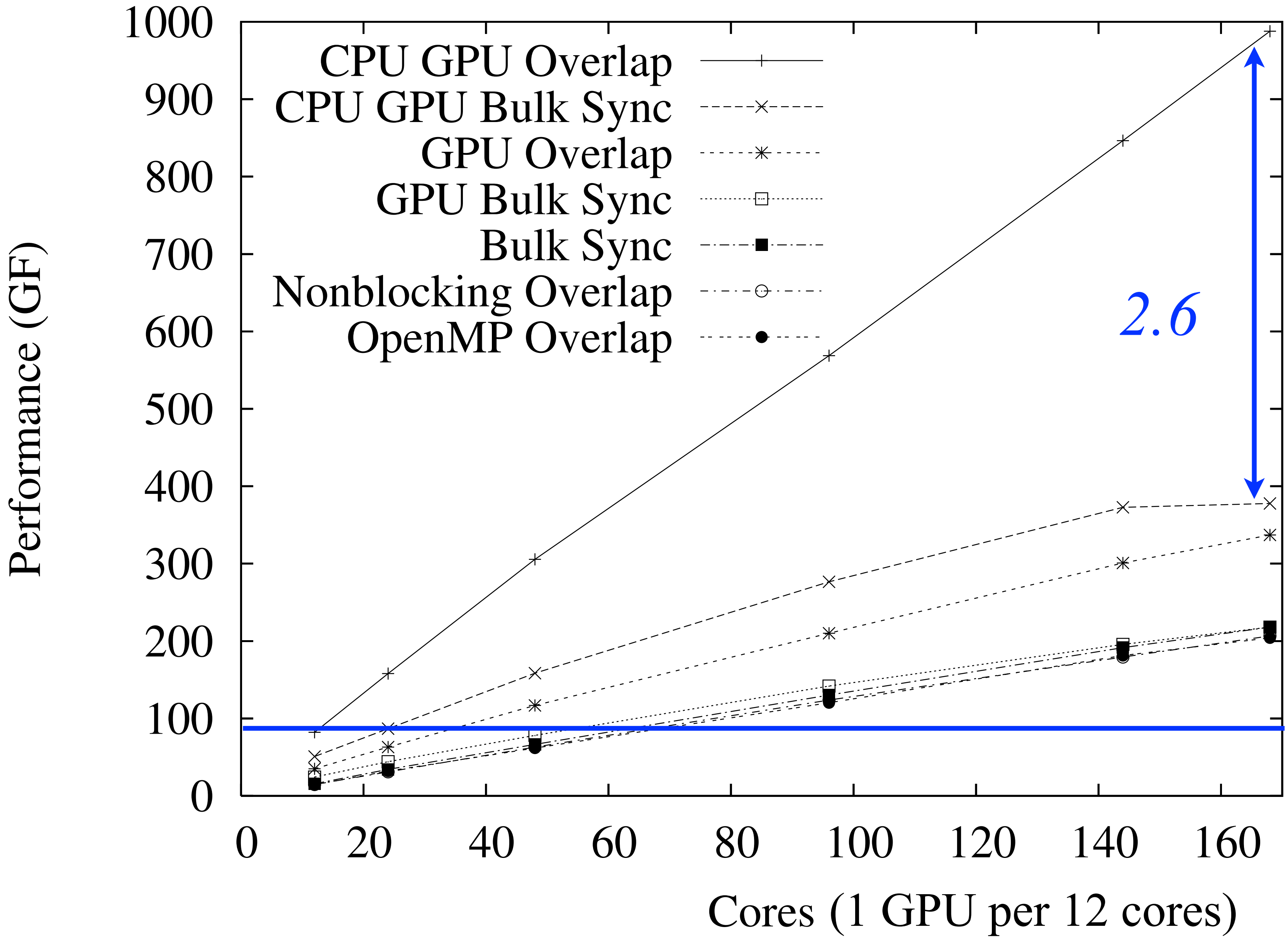
Best Performance on Lens



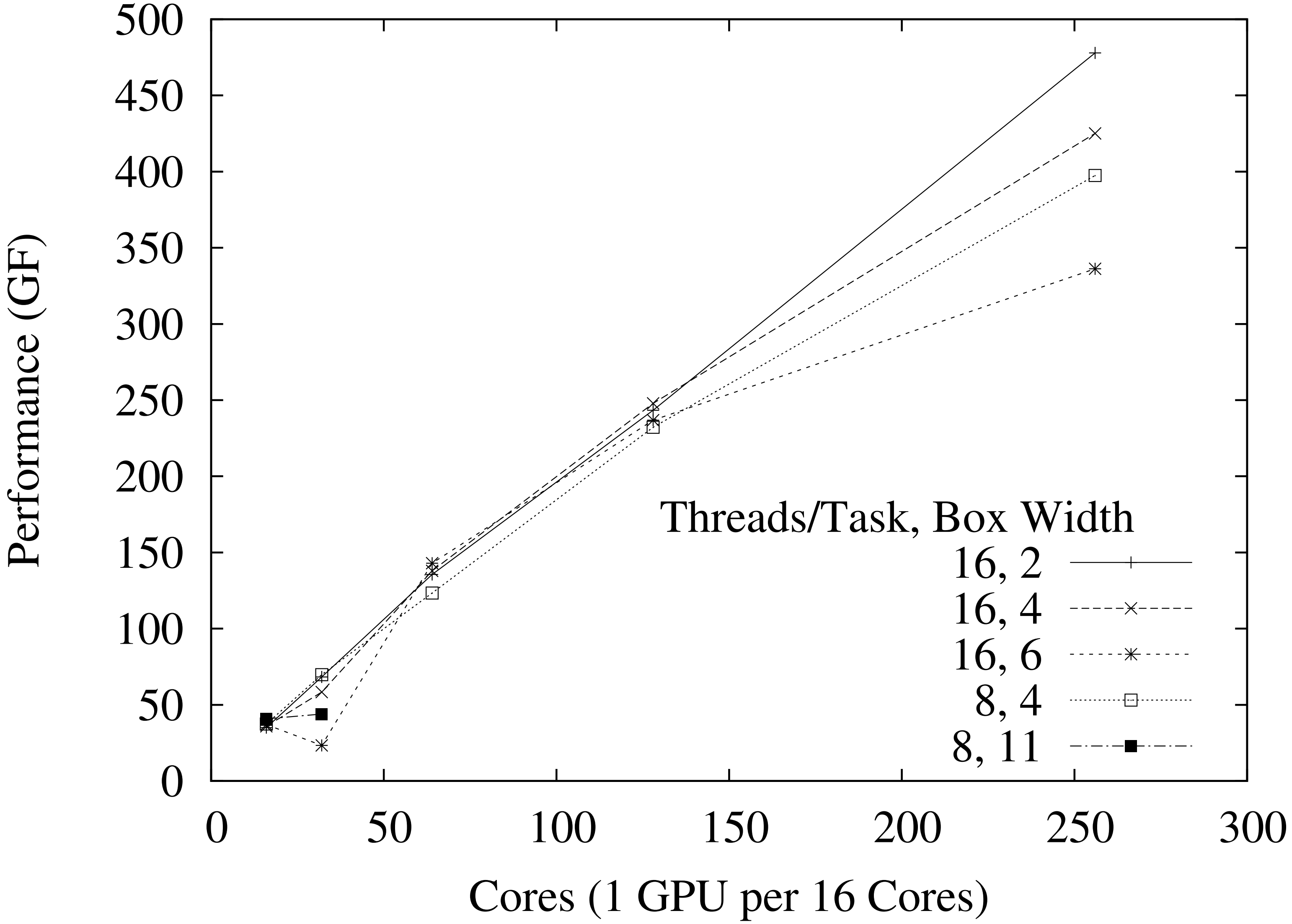
Best Performance on Yona



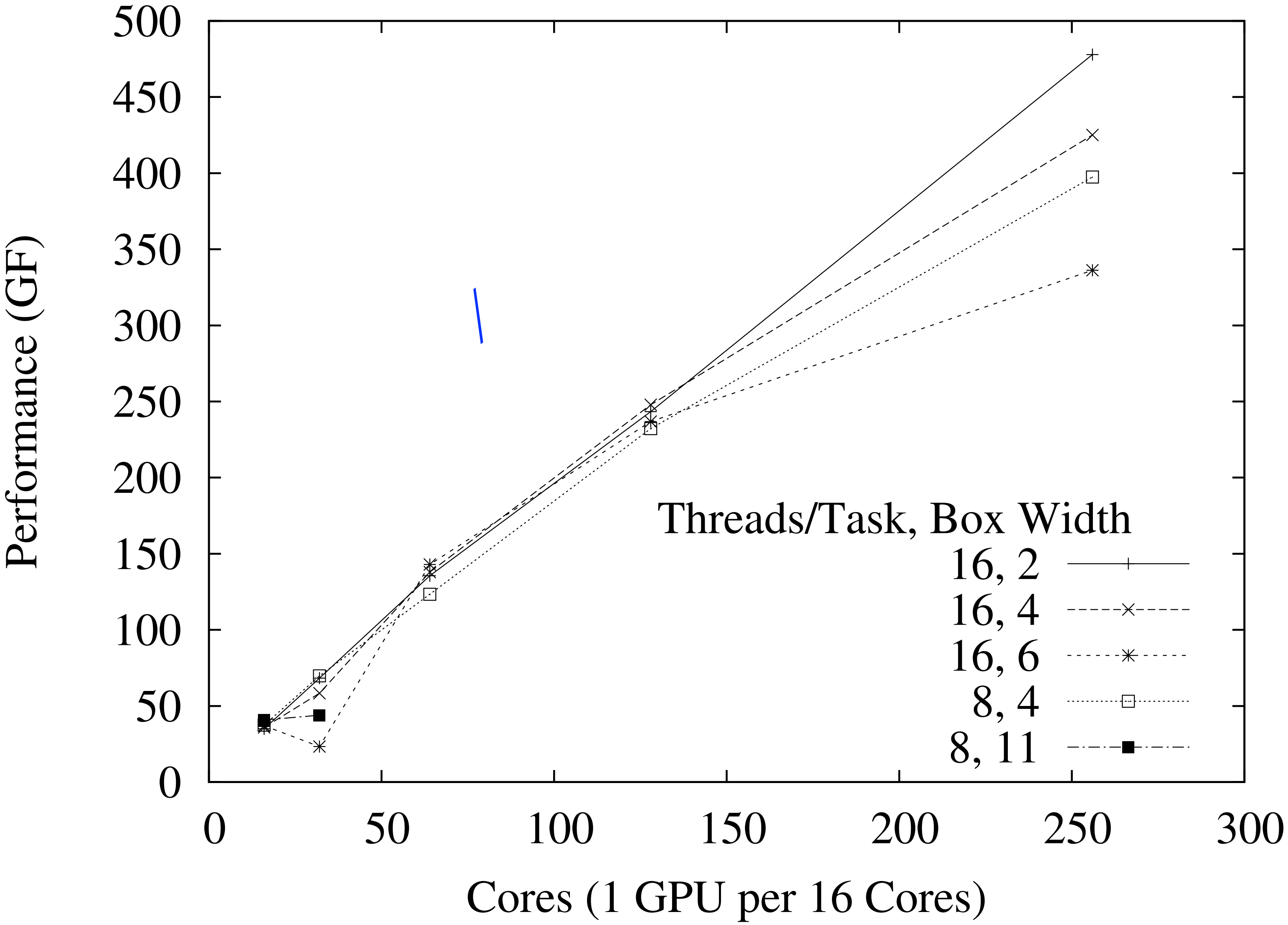
Best Performance on Yona



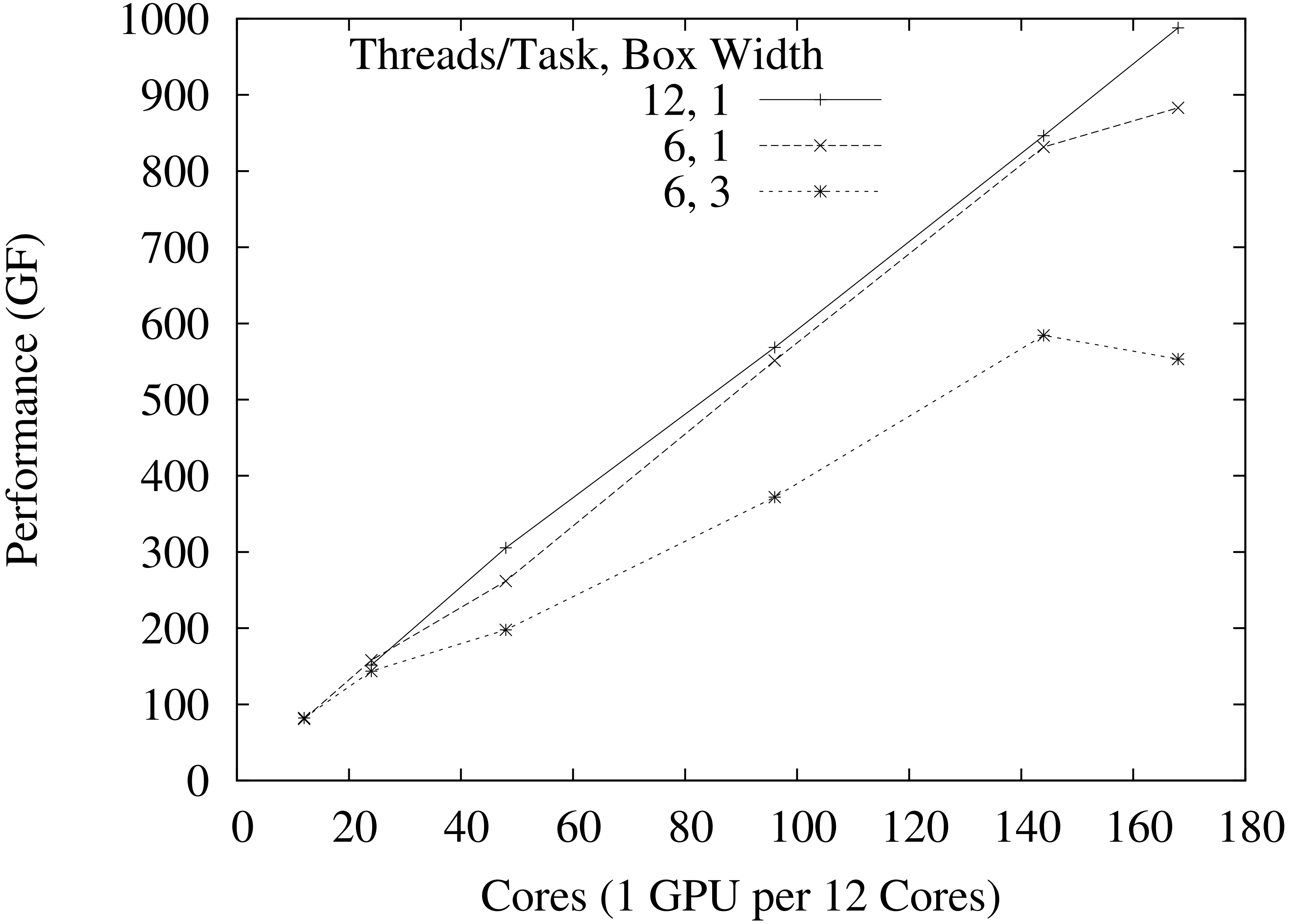
CPU-GPU Overlap Performance on Lens



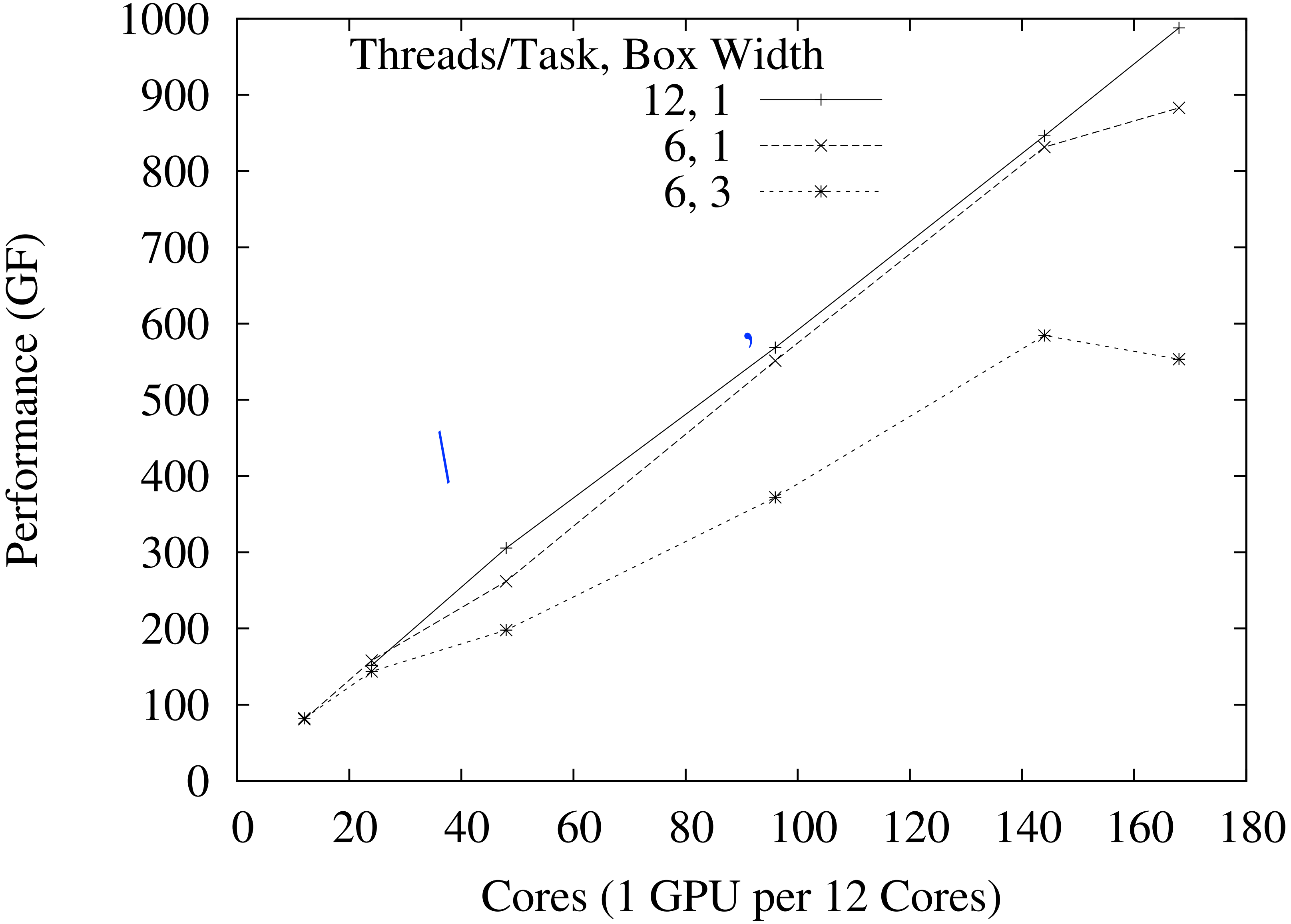
CPU-GPU Overlap Performance on Lens



CPU-GPU Overlap Performance on Yona



CPU-GPU Overlap Performance on Yona



Overlapping Computation and Communication for Advection on Hybrid Parallel Computers

- MPI overlap less important for this test
- But tuning threads/task ***is*** important
- Overlapping CPU computation, GPU computation, MPI communication, and CPU-GPU communication
  - Improves performance by more than 2x
  - Matches GPU-resident performance per GPU
- Best performance from giving minimal (but ***non-vanishing***) work to CPU
- Performance comes at a 4x cost in lines of code

Overlapping Computation and Communication for Advection on Hybrid Parallel Computers

James B White III (Trey)
trey@ucar.edu
National Center for Atmospheric Research

Jack Dongarra
dongarra@eecs.utk.edu
University of Tennessee, Knoxville

Programming Weather, Climate, and Earth-System Models
on Heterogeneous Multi-Core Platforms
NCAR, September 8, 2011

based on work first presented at IPDPS, Anchorage, AK, May 17, 2011

Portions of this work were funded by the Office of Biological and Environmental Research and the Office of Advanced Scientific Computing Research, both of the US Department of Energy. This research used resources of the OLCF at Oak Ridge National Laboratory and of NERSC at Lawrence Berkeley National Laboratory, both of which are supported by the Office of Science of the US Department of Energy.