PGI® COMPILERS &TOOLS

SC18 Dallas, TX | hpc inspires.

OPENMP GPU OFFLOAD IN FLANG AND LLVM

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NVIDIA.

MOTIVATION

What does HPC programmer need today?

- Performance → **GPUs**, multi-cores, other accelerators.
- Continuity → **Fortran!** Current and future large codes.
- Quick Porting → **OpenMP**, OpenACC, MPI etc.
- Cross platform compiler → **LLVM**, PGI, GNU, etc.

Conclusion, Fortran programmers needs

OpenMP GPU Offload in Flang

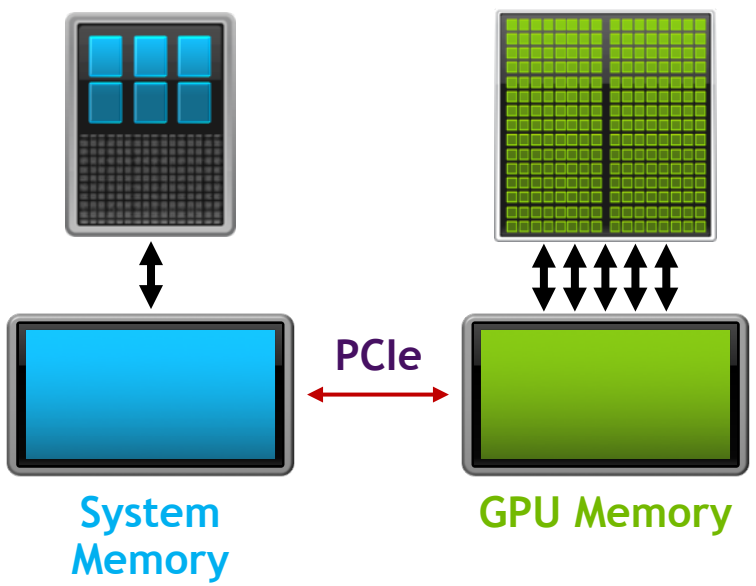
AGENDA

- Motivation
- **Background**
- Integration of OpenMP GPU Offload into Flang
- Experimental Evaluation
- Conclusion

Programming GPU-Accelerated Systems

Separate CPU System and GPU Memories

GPU Developer View



OPENMP 4.5

Device Offload Model

```
!$OMP TARGET ENTER DATA MAP(to:x, y)
```

copy array x, y
to the default device

```
!$OMP TARGET TEAMS DISTRIBUTE PARALLEL DO
DO i=1, n
  y(i) = a * x(i) + y(i)
ENDDO
```

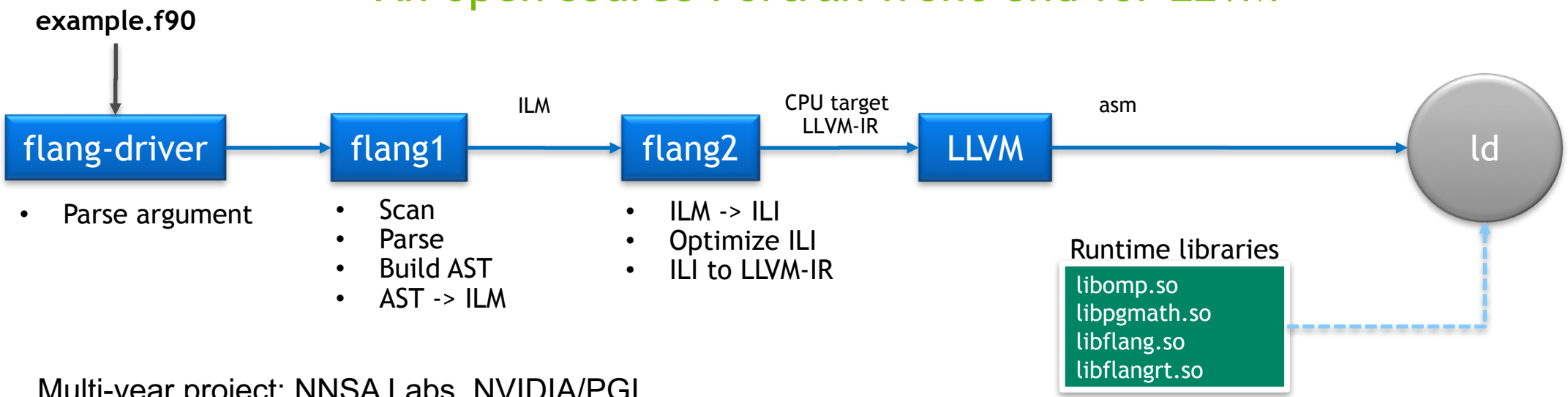
```
!$OMP TARGET EXIT DATA MAP(from: y)
```

copy array y
from the default
device

target:	Offload region
teams:	Create teams of threads
distribute:	Distribute the iteration across the master threads of all teams
parallel:	Create threads
do:	Distribute the iteration across the threads that already exist in the team

THE FLANG PROJECT

An open source Fortran front-end for LLVM



Multi-year project: NNSA Labs, NVIDIA/PGI

Based on the PGI Fortran front-end

Re-engineering for integration with LLVM

Develop CLANG-quality Fortran front end

Glossary
ILM: PGI-IR generated by frontend
ILI: PGI-IR generated by backend

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OPENMP GPU OFFLOAD IN FLANG

Design Goals

Provide an implementation of OpenMP 4.5 GPU Offload targeting NVIDIA GPUs in Flang

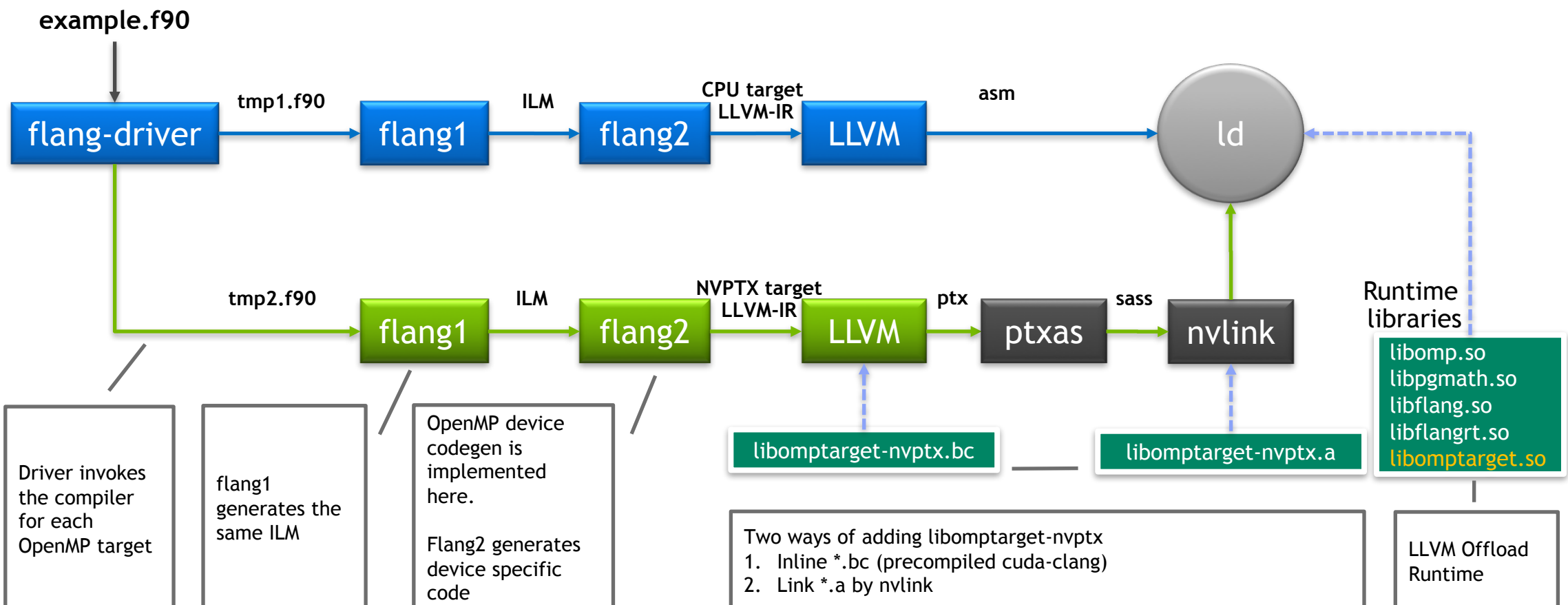
Aim to keep the same design as Clang OpenMP 4.5

- Leverage the Clang/LLVM driver
- Take advantage of LLVM's OpenMP runtimes

Compatibility with Flang and Clang OpenMP GPU Offload

COMPILATION PIPELINE

$ flang -fopenmp -fopenmp-targets=nvptx64-nvidia-cuda example.f90



CODE TRANSFORMATION

Example with OpenMP CPU

```
!$OMP TARGET TEAMS DISTRIBUTE
PARALLEL DO
DO i=1, n
  y(i) = a * x(i) + y(i)
ENDDO
```

- Use libomp(kmpc) as CPU OpenMP runtime
- Outline for each OpenMP construct

Generated LLVM-IR for Host target

```
define void @MAIN_ () {
  call void @targetFUNC(i32* %0, ...)
}
define internal void @targetFUNC(){
  call @__kmpc_fork_teams (... , %teamsFUNC)
  ret void
}
define internal void @teamsFUNC(){
  call void @__kmpc_for_static_init_4 (...)
  call void @__kmpc_fork_call(..., %parallelFUNC)
  call void @__kmpc_for_static_fini (...)
  ret void
}
define internal void @parallelFUNC(){
  call void @__kmpc_for_static_init_4 (...)
  ; <The loop body >
  call void @__kmpc_for_static_fini (...)
  ret void
}
```

Outlining for **$target**

Outlining for **$teams** & fork teams

Distribute loop across **$teams**

Outline for **$parallel** & fork threads

Distribute loop across **threads**

CODE TRANSFORMATION

Example with OpenMP GPU Offload

```
!$OMP TARGET TEAMS DISTRIBUTE
PARALLEL DO MAP(to:x) MAP(tofrom:y)
DO i=1, n
  y(i) = a * x(i) + y(i)
ENDDO
```

- Offload target region to the device
- New code transformation for device
- Use libomptarget for GPU offload
- Use libomptarget-nvptx in device OpenMP RT

Generated LLVM-IR for Host target

```
define void @MAIN_ () {
  call void @__tgt_target_teams(i8* %kernelID, ...)
}
```

Offload **$target** to GPU

Generated LLVM-IR for NVPTX target

```
define ptx_kernel void @kernel(){
  call @ teamsFUNC (...)
  ret void
}
define internal void @teamsFUNC(){
  call void @__kmpc_for_static_init_4 (...)
  call void @parallelFUNC(...)
  call void @__kmpc_for_static_fini (...)
  ret void
}
define internal void @parallelFUNC(){
  call void @__kmpc_for_static_init_4 (...)
  ; <The loop body >
  call void @__kmpc_for_static_fini (...)
  ret void
}
```

Outlining for **$teams** & call func

Distribute loop across **$teams**

Outline for **$parallel** & call func

Distribute loop across **threads**

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OUTLINER OPTIMIZATION

Reduce number of outlining for device code

Calling function in the device is not efficient

Omit outlining for combined constructs in device!

Generated LLVM-IR - Default

```
define ptx_kernel void @kernel(){
  call @ teamsFUNC (...)
  ret void
}
define internal void @teamsFUNC(){
  call void @__kmpc_for_static_init_4 (...) !$distribute
  call void @parallelFUNC(...)
  call void @__kmpc_for_static_fini (...)
  ret void
}
define internal void @parallelFUNC(){
  call void @__kmpc_for_static_init_4 (...) !$do
  ; <The loop body >
  call void @__kmpc_for_static_fini (...)
  ret void
}
```

Generated LLVM-IR - Reduced number of outlining in device

```
define ptx_kernel void @kernel(){
   call void @__kmpc_for_static_init_4 (...) ; !$distribute

   call void @__kmpc_for_static_init_4 (...) ; !$do
    ; <The loop body >
   call void @__kmpc_for_static_fini (...)

   call void @__kmpc_for_static_fini (...)
}
```

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EXPERIMENTAL EVALUATION

Compilers studied in our experiments

We run our experiments on IBM POWER8NVL and NVIDIA Pascal GPUs with CUDA 8.0

Compilers	Flags
Flang – OpenMP GPU (this work)	-O3 -fopenmp -fopenmp-targets=nvptx64-nvidia-cuda -Mpreprocess
Clang 7.0	-O3 -fopenmp -fopenmp-targets=nvptx64-nvidia-cuda
PGI 18.7	-Mpreprocess -fast -ta=tesla,cc60,cuda8.0 -mp
IBM XLF 16.0.1	-qsmp -qoffload -qpreprocessor -O3

EXPERIMENTAL EVALUATION (II)

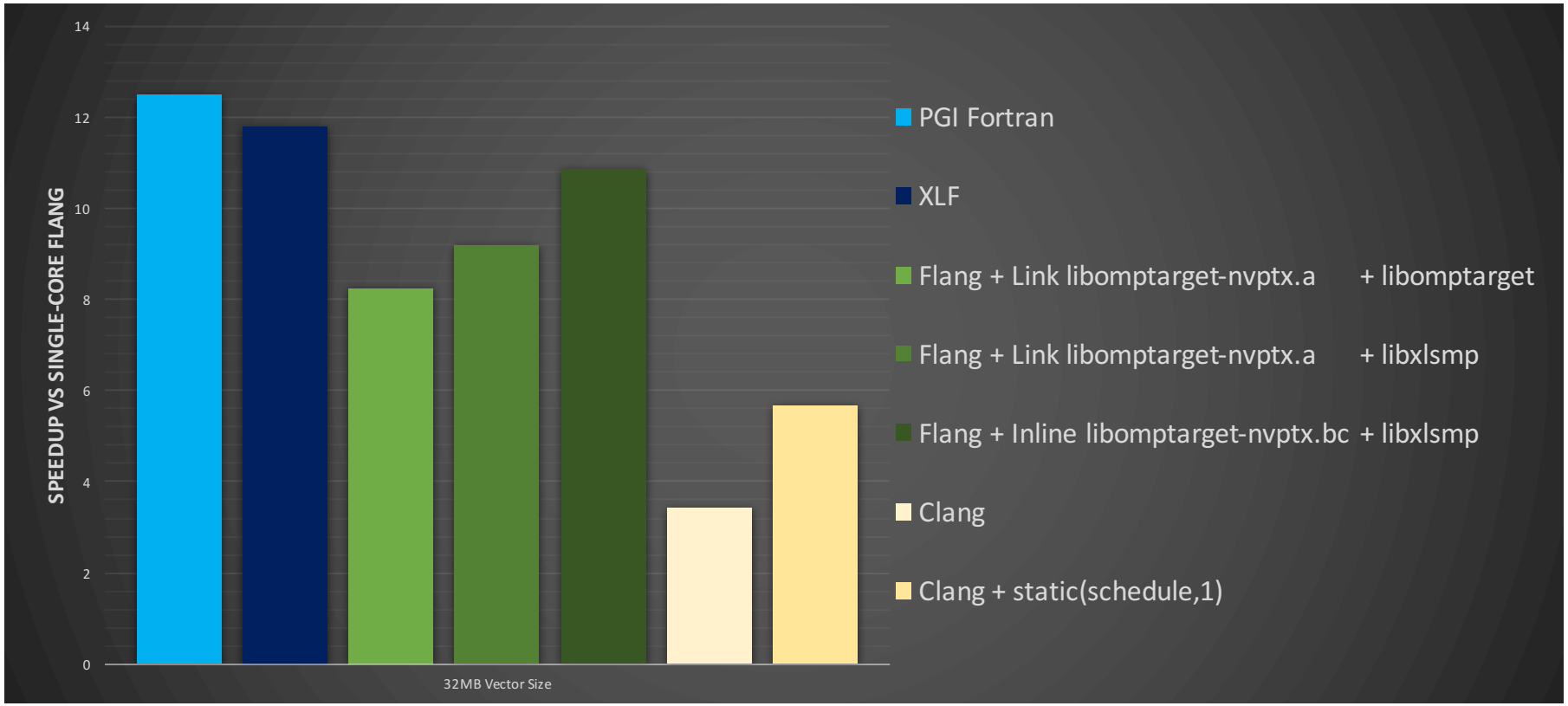
Compilers studied in our experiments

We experiment flang with different runtimes

Compiler	Target Offload Runtime	Device OpenMP Runtime
Flang	LLVM Offload RT - *libomptarget*	Compile device RT with nvcc Link *libomptarget-nvxptx*
Flang	IBM XL Offload RT - *libxlsmp*	Compile device RT with nvcc Link *libomptarget-nvxptx*
Flang	IBM XL Offload RT - *libxlsmp*	Compile device RT clang-cuda Inline *libomptarget-nvxptx.bc*

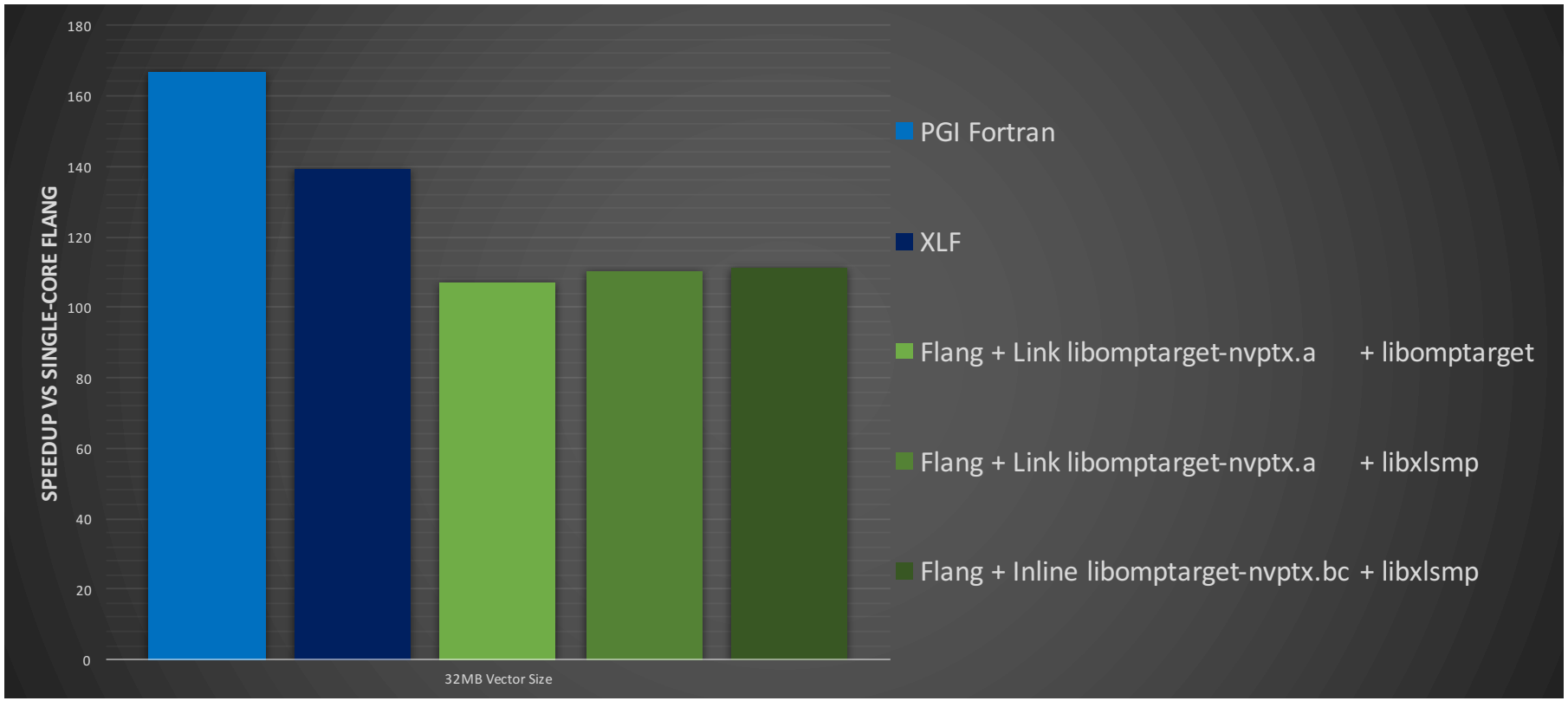
DAXPY

y = y *ax


SPEEDUP VS SINGLE-CORE FLANG
14
12
10
8
6
4
2
0
32MB Vector Size
PGI Fortran
XLF
Flang + Link libomptarget-nvptx.a + libomptarget
Flang + Link libomptarget-nvptx.a + libxlsmp
Flang + Inline libomptarget-nvptx.bc + libxlsmp
Clang
Clang + static(schedule,1)

360.ILBDC

Spec Accel



Performances are considered ESTIMATES per SPEC run and reporting rules.
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CONCLUSION

Flang OpenMP GPU Offload

- Introduced OpenMP GPU Offload to Flang
  - Support for combined-constructs
- Proposed compatible implementation with Clang
- Flang performance is in line with Clang
  - Obtained better performance with IBM XL's target offload runtime


NVIDIA