OAK RIDGE National Laboratory

OpenMP Offloading Features in LLVM 15

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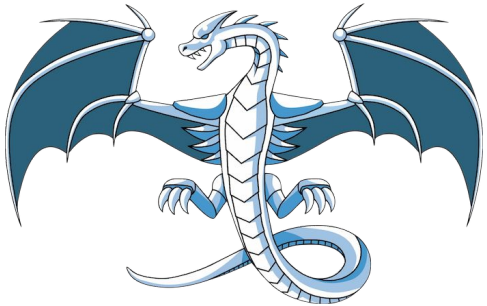
LLVM Release & Talk Overview

- LLVM 15 has been forked and contains several new features for offloading, incl.
  - A new compiler driver
  - Multi-Architecture binaries
  - Link Time Optimization
  - Static Library Support
  - OpenMP and CUDA / HIP interoperability
  - Extra flags improving offloading performance



OpenMP

Building LLVM with OpenMP offload

- Single command often suffices to configure:

  cmake llvm-project/llvm -DLLVM_ENABLE_PROJECTS='clang;lld' -DLLVM_ENABLE_RUNTIMES='openmp'
  make install -j

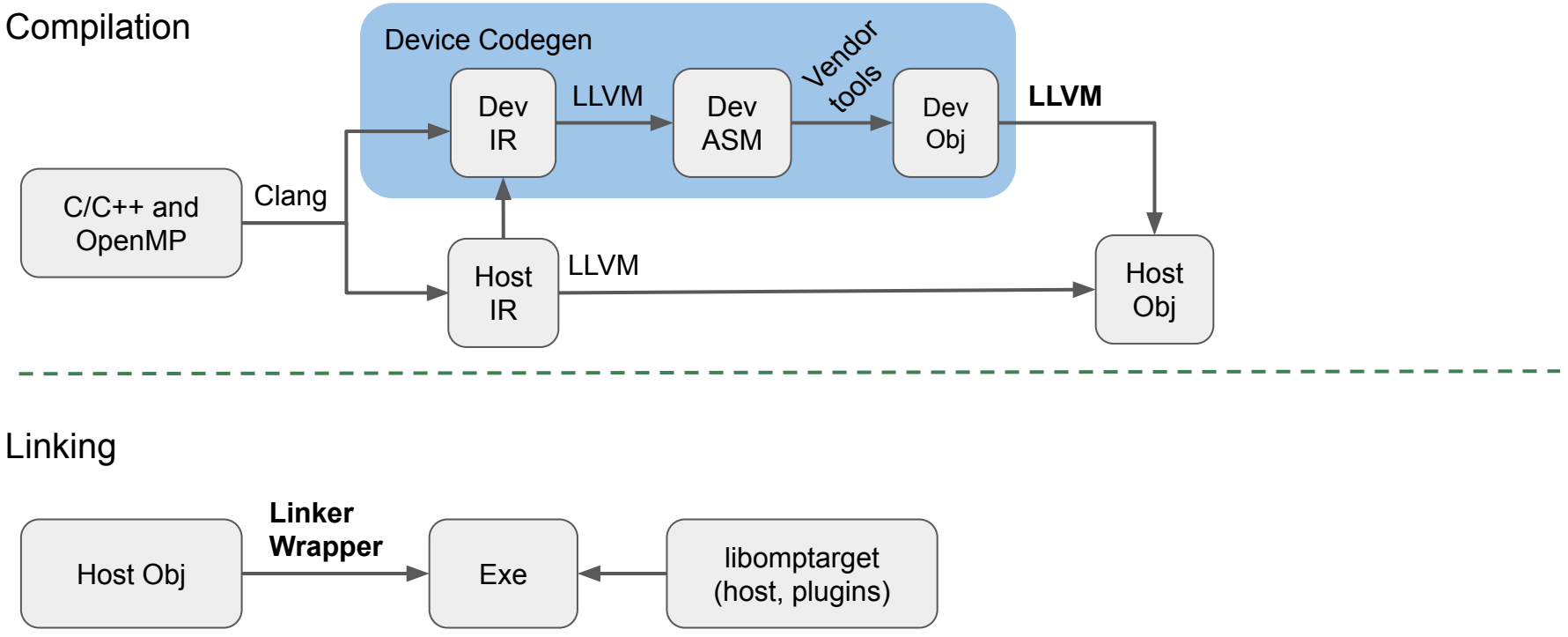
- Useful options include:

  CMAKE_BUILD_TYPE={Release,Asserts,…}
  LLVM_ENABLE_ASSERTIONS={ON,OFF}
  LLVM_CCACHE_BUILD={ON,OFF}
  -G Ninja

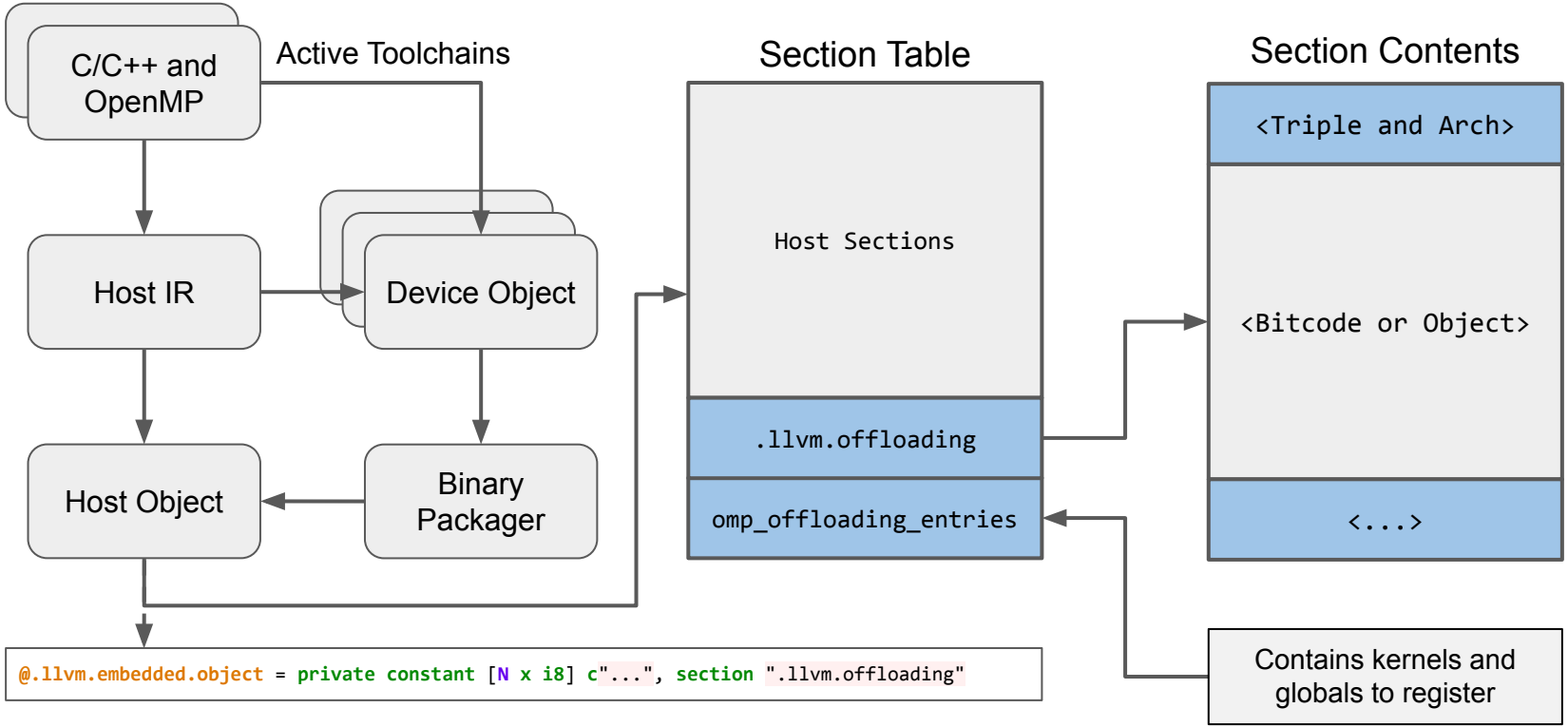
- Various resources available online! Start here:

  https://llvm.org/docs/GettingStarted.html
  https://openmp.llvm.org/SupportAndFAQ.html

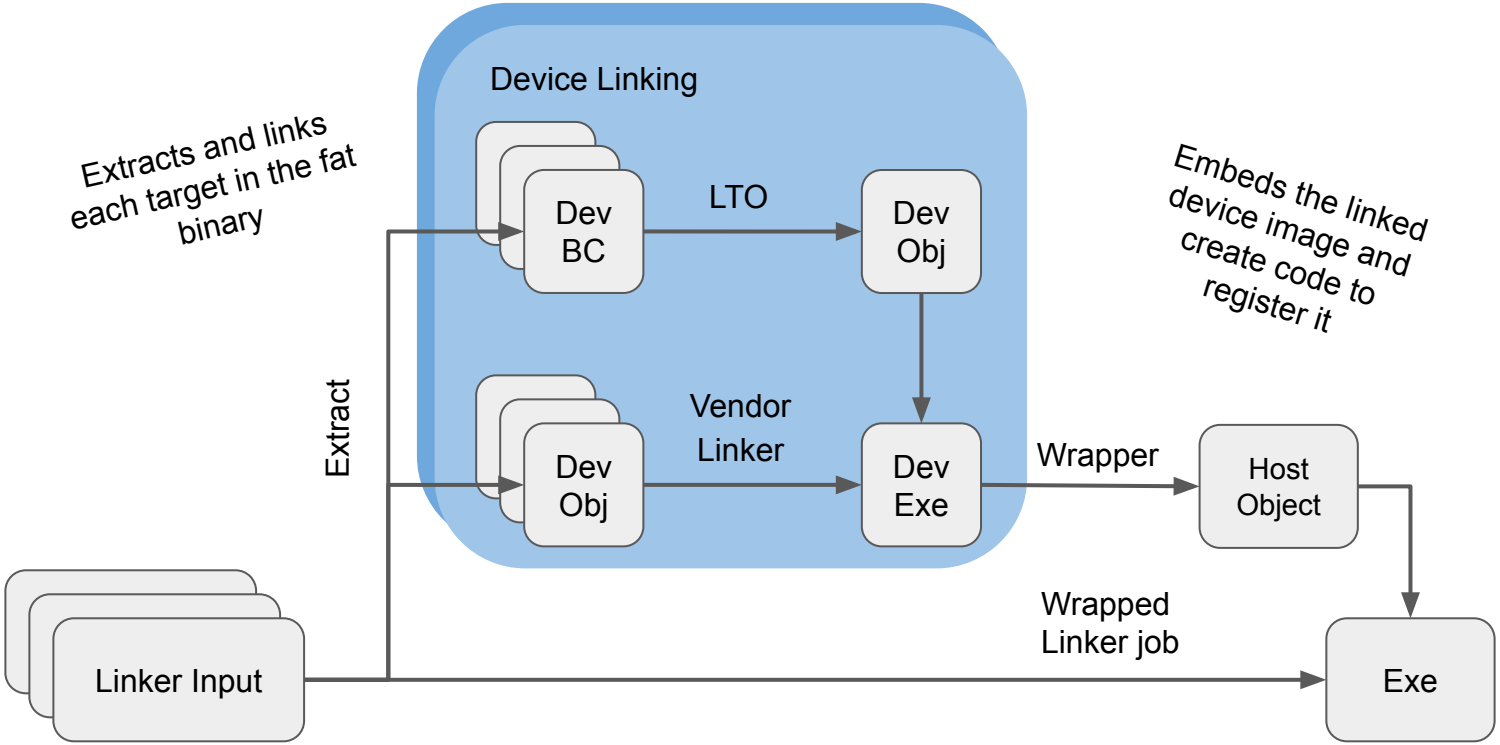
Compilation Phases w/ the New Driver



Embedding Device Code



Linker Wrapper



Multi-architecture Binaries

- LLVM now supports compiling for many architectures
  - Allows the same binary to run on several machines
- Without --fopenmp-targets we will try to infer the triples

```
$ clang app.c -fopenmp -fopenmp-targets=nvptx64,admgcn -c \
     -Xopenmp-target=nvptx64 --offload-arch=sm_80         \
     -Xopenmp-target=amdgcn --offload-arch=gfx90a
$ clang app.c -fopenmp --offload-arch=sm_80 --offload-arch=gfx90a -c
$ llvm-readelf -S app.o
Section Headers:
[Nr] Name              Type            Address          Off    Size   ES Flg Lk Inf Al
[11] .llvm.offloading LLVM_OFFLOADING 0000000000002058 002058 0024c0 00 E   0  0   8
[12] omp_offloading_entries PROGBITS  0000000000005048 004048 000020 00 A   0  0   8
```

Multi-architecture Binaries

- Can inspect the embedded device code with binary utils

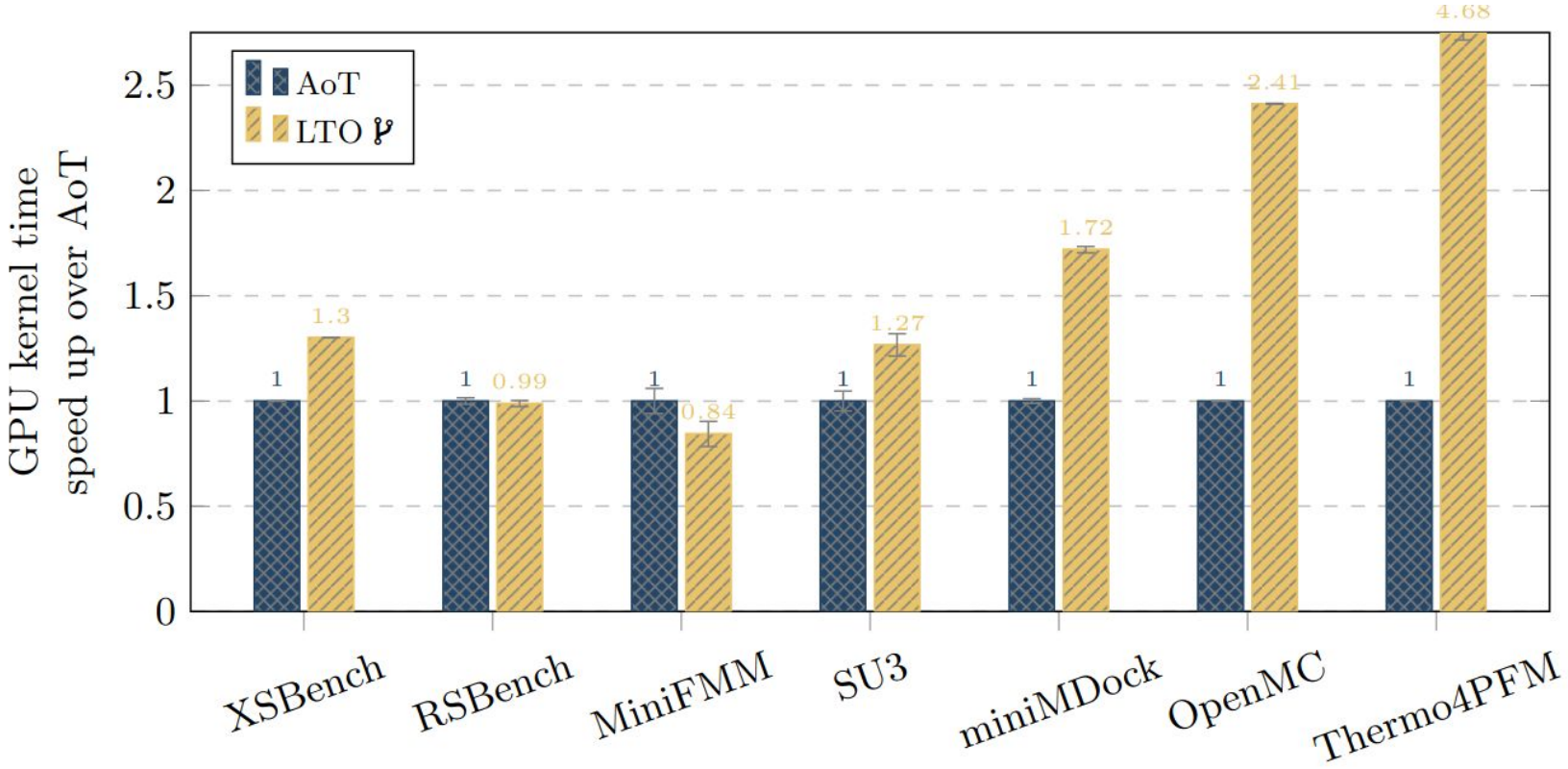
```
$ clang app.c -fopenmp --offload-arch=sm_80 --offload-arch=gfx90a -o app
$ llvm-objdump --offloading ./app
OFFLOADING IMAGE [0]:
kind elf
arch gfx90a
triple amdgcn-amd-amdhsa
producer openmp

OFFLOADING IMAGE [1]:
kind elf
arch sm_80
triple nvptx64-nvidia-cuda
producer openmp
```

Link Time Optimization (LTO)

- Compilers normally optimize a single translation unit (TU) at a time
  - LTO allows the compiler to optimize the whole program
- LLVM now supports LTO for the device
- Currently needs to be specified for both

```
$ clang app.c -fopenmp -fopenmp-targets=nvptx64 -foffload-lto -O3 -c
$ clang app.o -fopenmp -fopenmp-targets=nvptx64 -foffload-lto -O3
```

LTO Performance Improvement (A100 Nvidia GPU)



Static Library Support

- LLVM now completely supports static libraries
  - Any method of creating static libraries should work now
- The linker only imports used symbols from static libraries
  - Somewhat inherit this behaviour for multi-architecture binaries

```
$ clang foo.c -fopenmp --offload-arch=sm_70 --offload-arch=sm_80 --offload-arch=gfx908 -c
$ llvm-ar rcs libfoo.a foo.o
$ clang app.c -fopenmp --offload-arch=sm_70 -lfoo -o app
$ llvm-objdump --offloading
OFFLOADING IMAGE [0]:
kind elf
arch sm_70
triple nvptx64-nvidia-cuda
producer openmp
```

Static Library Support

- Can use this to create generic libraries
  - LTO can create zero overhead libraries

```
#pragma omp begin declare target device_type(nohost)

#pragma omp begin declare variant match(...)
void foo() {...}
#pragma omp end declare variant

#pragma omp end declare target
```

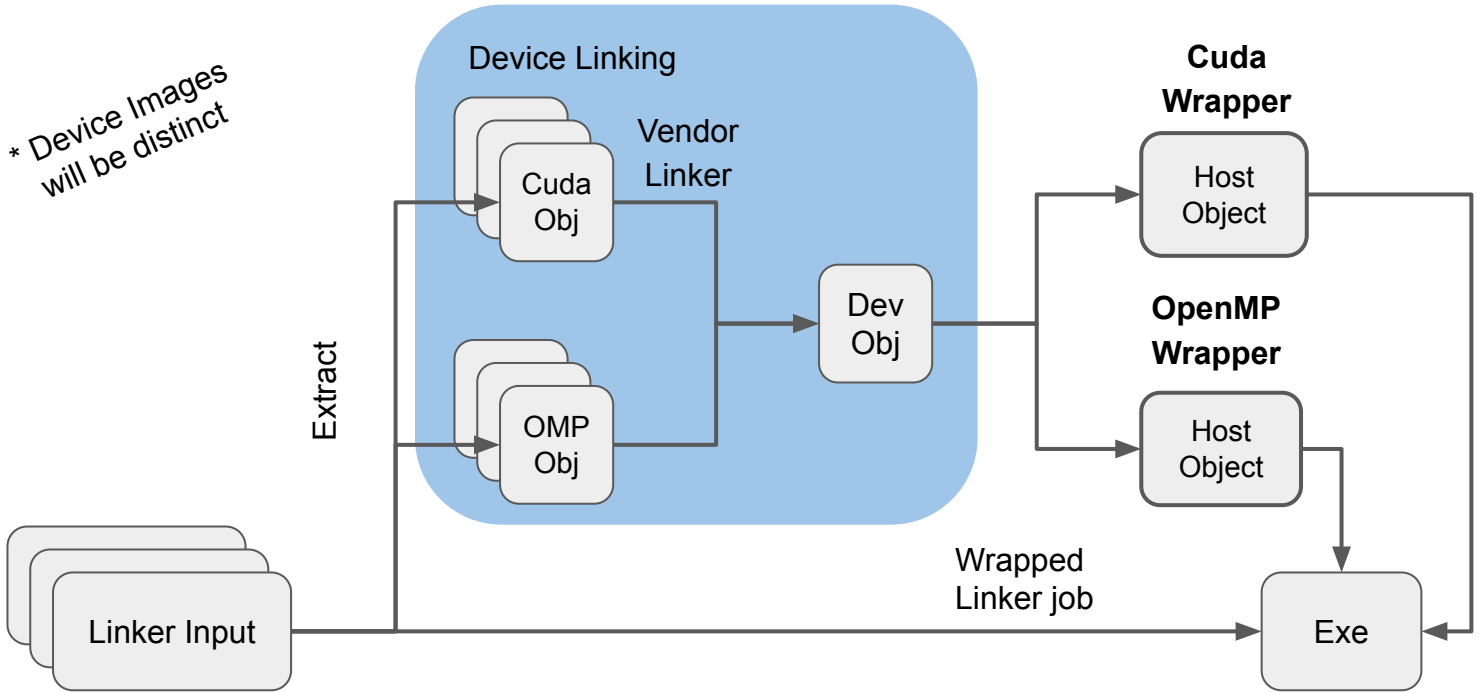
```
$ clang device.c -fopenmp --offload-arch=sm_52,sm_70,sm_80,gfx908,gfx90a,gfx90c -O3 \
    -foffload-lto -fvisibility=hidden -fopenmp-cuda-mode
$ llvm-ar rcs libdevice.a device.o
$ clang app.c -fopenmp --offload-arch=sm_80 -foffload-lto -ldevice
```

CUDA / HIP Interoperability

- The new driver can compile both CUDA and HIP
  - Requires explicitly using the new Driver
- LLVM now supports CUDA compilation in RDC-mode
  - Previously required external build systems

```
$ clang++ cuda.cu util.cu -fgpu-rdc --offload-arch=sm_70 --offload-new-driver -c
$ clang++ cuda.o util.o --offload-link -lcudart -o app
$ ./a.out
```

Linker Wrapper



CUDA / HIP Interoperability

- OpenMP interoperability with CUDA / HIP objects
  - Caveat: Global state is not yet shared
  - Would require having all state registered by OpenMP Or CUDA

```
void openmp() { printf ("Hello from OpenMP\n"); }
#pragma omp declare target device_type(nohost) to(openmp)

__device__ cuda() { printf ("Hello from CUDA\n"); }
```

```
$ clang++ cuda.cu -fgpu-rdc --offload-arch=sm_70 --offload-new-driver -c
$ clang++ openmp.cpp -fopenmp --offload-arch=sm_70 -c
$ clang++ cuda.o openmp.o -fopenmp -fopenmp-targets=nvptx64 -lcudart
./a.out
Hello from OpenMP
Hello from CUDA
```

Device Only Compilation

- Device only compilation output the device result
  - Caveat: Can only output a single architecture currently
- Mainly useful for inspecting output

```
$ clang app.c -fopenmp --offload-arch=sm_70 -S -emit-llvm --offload-device-only -o -
< LLVM IR >
```

Mandatory Offloading

- OpenMP offloading supports host-fallback by default
- This requires emitting each device function on the host
- Can be disabled using a command line flag
  - Makes interoperability with CUDA easier.

```
$ clang app.c -fopenmp --offload-arch=sm_70 -fopenmp-offload-mandatory
```

Passing Arguments to the Device Linker

- The linker wrapper links many devices in a single invocation
- Extra arguments can be forwarded to the device linker if needed

```
$ clang app.c -fopenmp --offload-arch=sm_70 -Xoffload-linker -g
$ clang app.c -fopenmp --offload-arch=sm_70 -Xoffload-linker-nvptx64-nvidia-cuda -g
```

No Thread State Assertions

- The OpenMP GPU runtime supports standard OpenMP
  - Some features are difficult to optimize out and costly
- We provide a flag to manually disable thread state
  - Used for features like nested parallelism and tasking
  - Should hopefully not be required once we have more advanced optimizations
- Should improve application performance

```
$ clang app.c -fopenmp --offload-arch=gfx90a -fopenmp-assume-no-thread-state
```

Questions?