Enabling CHIP-SPV in Chapel GPUAPI module

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MOTIVATION

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GPU Programming in Chapel: no “intermediate” programming model

Highest-level Chapel-GPU Programming

```
forall i in 1..n {
  A(i) = B(i) + alpha * C(i);
}
```

A huge gap!

Lowest-level Chapel-GPU Programming
(C Interoperability only or GPUIterator)

```
// separate C file
__global__ void stream(float *dA, float *dB, float *dC,
                       float alpha, int N) {
    int id = blockIdx.x * blockDim.x + threadIdx.x;
    if (id < N) {
            dA[id] = dB[id] + alpha * dC[id];
    }
}
void GPUST(float *A, float *B, float *C, float alpha,
           int start, int end, int GPUN) {
  float *dA, *dB, *dC;
  CudaSafeCall(cudaMalloc(&dA, sizeof(float) * GPUN));
  CudaSafeCall(cudaMalloc(&dB, sizeof(float) * GPUN));
  CudaSafeCall(cudaMalloc(&dC, sizeof(float) * GPUN));
  CudaSafeCall(cudaMemcpy(dB, B + start, sizeof(float) *
                          GPUN, cudaMemcpyHostToDevice));
  CudaSafeCall(cudaMemcpy(dC, C + start, sizeof(float) *
                          GPUN, cudaMemcpyHostToDevice));

  stream<<<ceil(((float)GPUN)/1024), 1024>>>
                                    (dA, dB, dC, alpha, GPUN);
  CudaSafeCall(cudaDeviceSynchronize());
  CudaSafeCall(cudaMemcpy(A + start, dA, sizeof(float) *
                          GPUN, cudaMemcpyDeviceToHost));
  CudaSafeCall(cudaFree(dA));
  CudaSafeCall(cudaFree(dB));
  CudaSafeCall(cudaFree(dC));
}
```

Research Question:
What is an appropriate and portable programming interface that bridges the ”forall” and GPU versions?

Big Picture: A Multi-level Chapel GPU Programming Model

HIGH-level:
The compiler compiles forall to CUDA, HIP, and OpenCL

forall

The missing link

Our proposal

Chapel programmer friendly GPU APIs :
MID-level

```
var dA = new GPUArray(A);
dA.toDevice();
```

Thin wrappers for low-level GPU APIs:
MID-LOW-level

```
Malloc(); Memcpy();
```

Goal: increase productivity with no performance loss

LOW-level:
The user prepares full GPU programs and invokes them from Chapel (w/ or w/o the GPUIterator)

C Interoperability | GPUIterator [1]

CUDA/HIP/OpenCL

NVIDIA/AMD/Other GPUs

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[1] Akihiro Hayashi, Sri Raj Paul, Vivek Sarkar
“GPUIterator: Bridging the gap between Chapel and GPU Platforms” (CHIUW’19)

Contributions

- Why higher-level abstraction of GPU API?
  - For improving productivity

    Our observation: The complexity in GPU programming comes not only from writing GPU kernels in the device part, but also from writing the host part

    ✓ Our GPUAPI is designed to simplify the host part
  - For improving portability

    Our observation: There are different GPU programming models from different vendors

    ✓ Our GPUAPI is implemented to work on different platforms (NVIDIA, AMD, Intel, …)
- Contribution (specific to this talk):
  - Enhance support for Intel GPUs by implementing a CHIP-SPV backend in the GPUAPI module

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Enabling CHIP-SPV in Chapel GPUAPI module

THE GPUAPI MODULE

Summary of the Chapel GPUAPI module

- Use case:
  - The user would like to 1) write GPU kernels, or 2) utilize highly-tuned GPU libraries, and would like to stick with Chapel for the other parts (allocation, data transfers)
- Provides two levels of GPU API
  - MID-LOW: Provides wrapper functions for raw GPU APIs

    Example: `var ga: c_void_ptr = GPUAPI.Malloc(sizeInBytes);`
  - MID: Provides more user-friendly APIs

    Example: `var ga = new GPUArray(A);`
- Note
  - The user is still supposed to write kernels in CUDA/HIP/SYCL (DPC++)
  - The APIs significantly facilitates the orchestration of:
    - ✓ Device memory (de)allocation, and host-to-device/device-to-host data transfers,
  - The use of the APIs does not involve any modifications to the Chapel compiler
  - The module can be utilized in real-world Chapel applications such as Champs and ChOp

Example: Distributed execution of STREAM (MID-level w/ GPUIterator)

```
var D: domain(1) dmapped Block(boundingBox={1..n}) = {1..n};
var A: [D] real(32);
var B: [D] real(32);
var C: [D] real(32);
var GPUCallBack = lambda (lo: int, hi: int, nElems: int) {
  var dA = new GPUArray(A.localSlice(lo..hi));
  var dB = new GPUArray(B.localSlice(lo..hi));
  var dC = new GPUArray(C.localSlice(lo..hi));
  toDevice(dB, dC);
  LaunchST(dA.dPtr(), dB.dPtr(),
           dC.dPtr(), alpha,
           dN: size_t);
  DeviceSynchronize();
  FromDevice(dA);
  Free(dA, dB, dC);
};
forall i in GPU(D, GPUCallBack,
                   CPUPercent) {
  A(i) = B(i) + alpha * C(i);
}
```

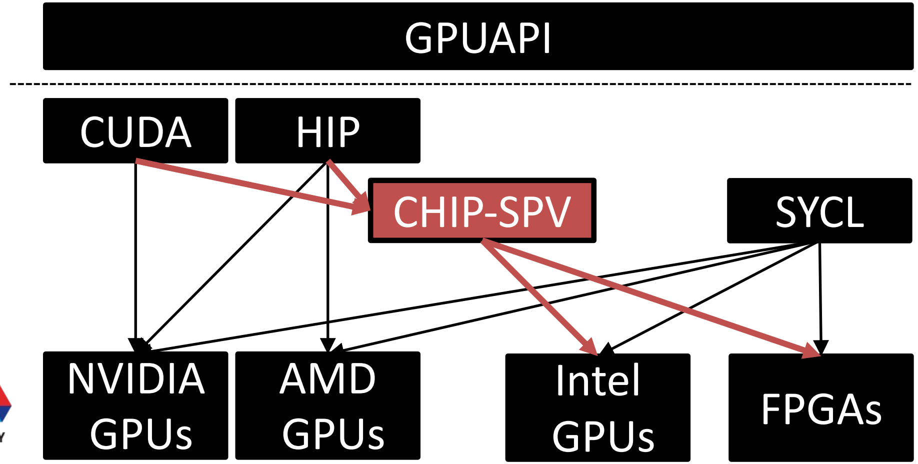
Chapel's Distributed Array Allocation (n divided by # of nodes float elements)

The user has the option of writing device functions, device lambdas, or library calls

```
// separate C file (CUDA w/ device lambda)
void LaunchST(float *dA, float *dB,
              float *dC, float alpha, int N) {
  GPU_FUNCTOR(N, 1024, NULL,
    [=] __device__ (int i) {
      dA[i] = dB[i] + alpha * dC[i];
    });
}
```

Multi-platform Support: Module implementation

- ❑ Our module supports a wide variety of GPUs
- ❑ Our cmake-based build system detects types of GPUs and generate corresponding static and shared libraries
  - libGPUAPIX_static.a and libGPUAPIX.so
    - ✓ X = CUDA, HIP, or DPCPP



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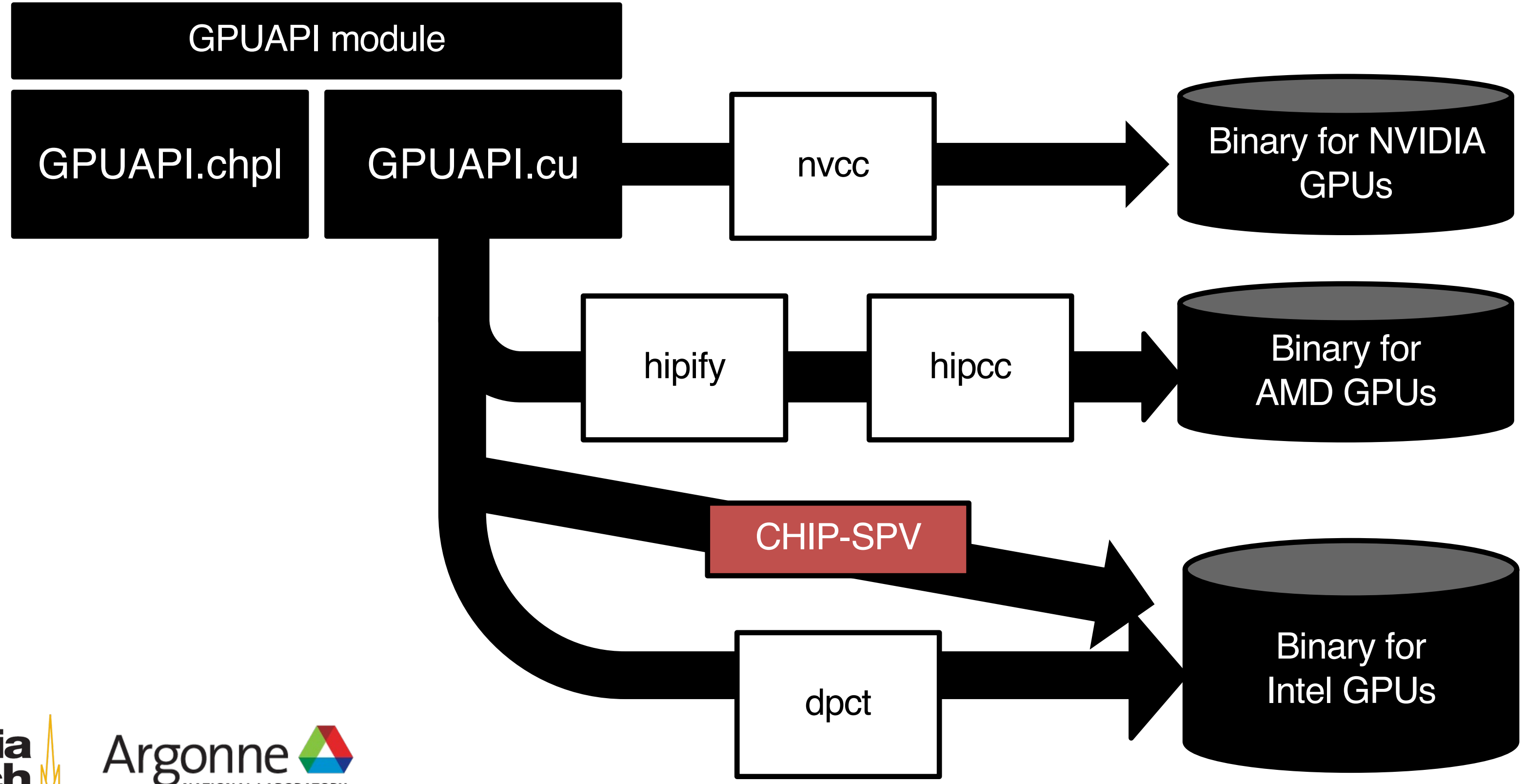
Multi-platform Support: Module implementation



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Multi-platform Support: User-written kernels

- Our multi-platform GPUAPI support allows the user to choose any GPU programming models to write their kernel code

	CUDA	HIP	SYCL
NVIDIA	Yes	Yes	Yes
AMD	Yes (hipify)	Yes	Yes
Intel	Yes (dpct or CHIP-SPV)	Yes (CHIP-SPV)	Yes

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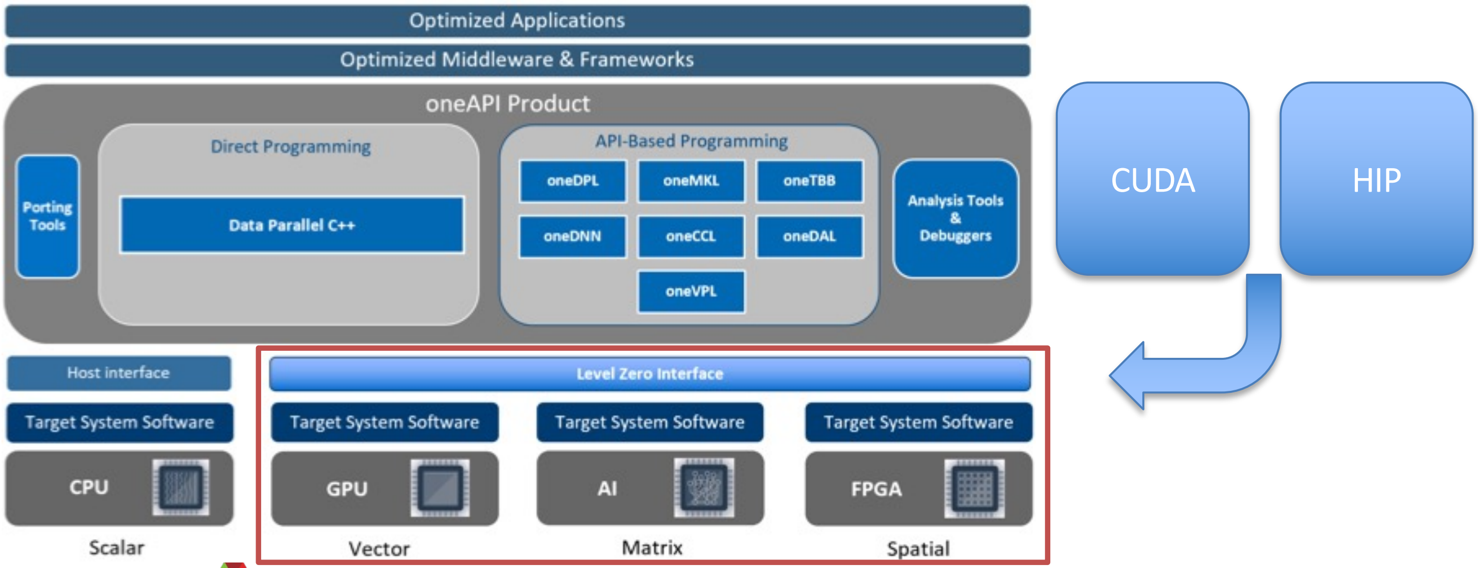
CHIP-SPV

CHIP-SPV

- Connect heterogeneous programming models (CUDA/HIP) to low-level Intel Level Zero runtime
- Intel Level Zero: A system level programming interface that bridges high level libraries to Intel devices



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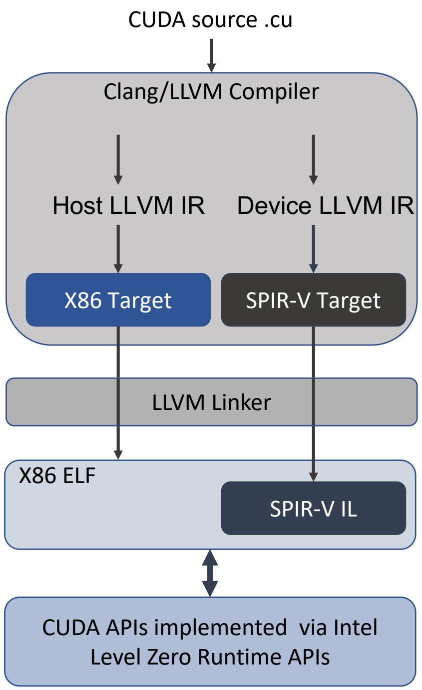
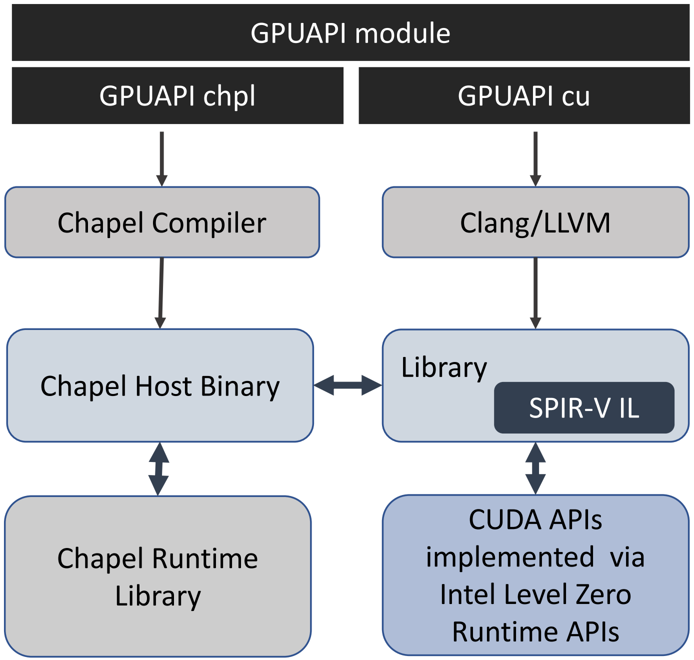
CHIP-SPV in the GPUAPI module





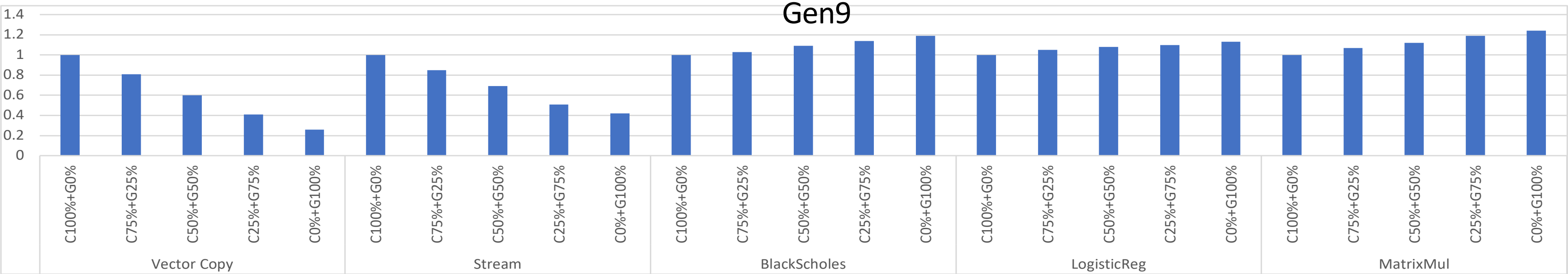
Enabling CHIP-SPV in Chapel GPUAPI module

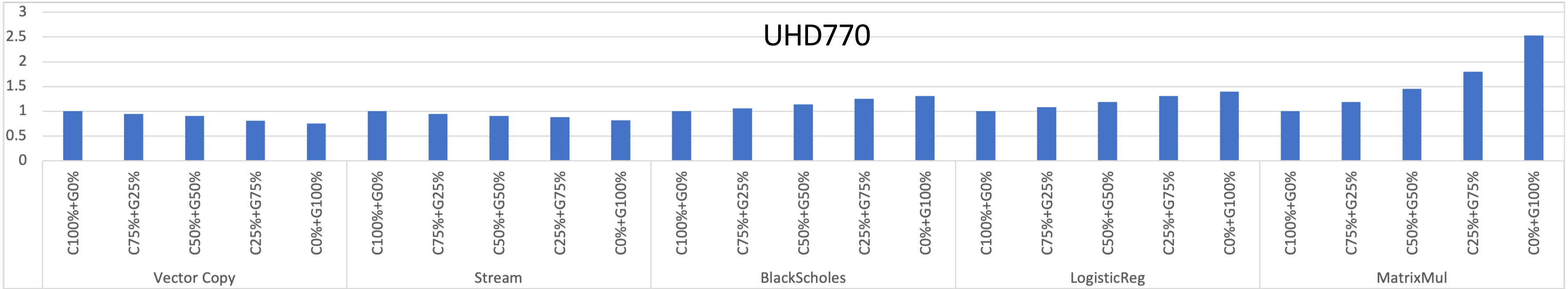
PRELIMINARY PERFORMANCE EVALUATIONS

Performance Evaluations

- Platforms (Single-node, integrated-GPUs)
  - Intel Xeon Processor E5-1585 v5 (4-core) + Iris Pro P580 (Gen9)
  - Intel i7-12700 + UHD770
- Applications
  - Micro-benchmark: STREAM, BlackScholes, Matrix Multiplication, Logistic Regression
- Chapel Compilers & Options
  - Chapel Compiler 1.29.0 with the --fast option
  - Used with the GPUIterator (CPU+GPU execution)

Preliminary Performance Numbers (vs. forall execution on CPUs)





- Key take aways:
  - Our end-to-end compilation flow with CHIP-SPV is verified
  - Performance improvements are not significant due to integrated GPUs, but this is where the GPUIterator module comes into play

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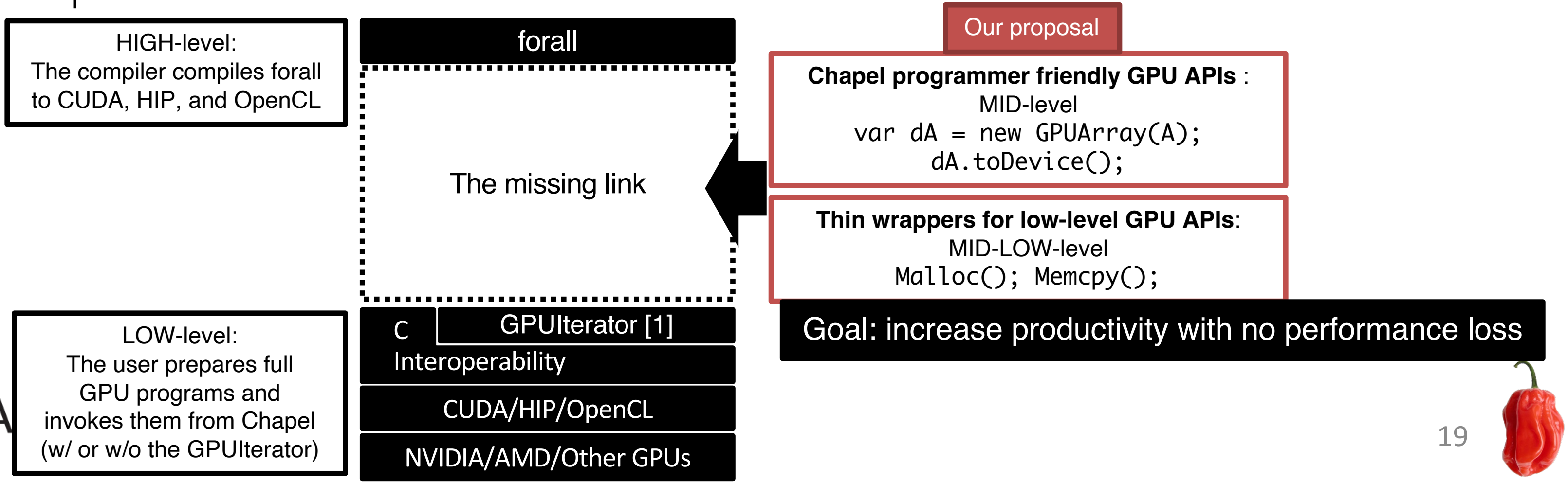
CONCLUSIONS

Conclusions

- Intel GPUs support in the GPUAPI module
  - Verified with microbenchmarks on two intel GPU platforms
- Future work:
  - Use discrete Intel GPUs
  - Discuss the possibility of using CHIP-SPV in the current Chapel compiler



Join our community

- GPUAPI+GPUIterator:
  - The repository
    - ✓ https://github.com/ahayashi/chapel-gpu
  - Detailed Documents
    - ✓ https://ahayashi.github.io/chapel-gpu/index.html
- Our community is growing!

Contact: ahayashi "at" gatech.edu

Acknowledgements

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BACKUP SLIDES

Chapel GPU API Design: MID-LOW GPU API

- Summary
  - Provides the same functionality as CUDA/HIP/OpenCL
  - The user is still supposed to write CUDA/HIP/OpenCL kernels
  - The user is supposed to handle both C types and Chapel types
- Key APIs
  - Device Memory Allocation
    - ✓ `Malloc(…);`
    - ✓ `MallocPitch(…);`
  - Host-to-device, and device-to-host data transfers
    - ✓ `Memcpy(…);`
    - ✓ `Memcpy2D(…);`
  - Ensuring the completion of GPU computations
    - ✓ `DeviceSynchronize();`
  - Device Memory deallocation
    - ✓ `Free(…);`

Chapel GPU API Design: MID GPU API

- Summary
  - More natural to Chapel programmers
  - The user is still supposed to write CUDA/HIP/OpenCL kernels
- Key APIs
  - Device Memory Allocation
    - ✓ `var dA = new GPUArray(A);`
    - ✓ `var dA = new GPUJaggedArray(A);`
  - Host-to-device, and device-to-host data transfers
    - ✓ `ToDevice(dA:GPUArray, …); FromDevice(dA: GPUArray, …);`
    - ✓ `dA.ToDevice(); dA.fromDevice();`
  - Implicit Device Memory deallocation
    - ✓ Automatically “freed” when a GPUArray/GPUJaggedArray object is deleted
  - Explicit Device Memory deallocation
    - ✓ `delete`

Chapel GPU API Design: MID-LOW/MID GPU API Example

MID-LOW Level

```
use GPUAPI;
var A: [1..n] real(32);
var B: [1..n] real(32);
var C: [1..n] real(32);
var dA, dB, dC: c_void_ptr;
var size: size_t =
   (A.size:size_t * c_sizeof(A.eltType));
Malloc(dA, size);
Malloc(dB, size);
Malloc(dC, size);
Memcpy(dB, c_ptrTo(B), size, TODEVICE);
Memcpy(dC, c_ptrTo(C), size, TODEVICE);
LaunchST(dA, dB, dC, alpha, N: size_t);
DeviceSynchronize();
Memcpy(c_ptrTo(A), dA, size, FROMDEVICE);
Free(dA); Free(dB); Free(dC);
```

Chapel's Array Allocation (n float elements)

MID-level

```
use GPUAPI;
var A: [1..n] real(32);
var B: [1..n] real(32);
var C: [1..n] real(32);
var dA = new GPUArray(A);
var dB = new GPUArray(B);
var dC = new GPUArray(C);
toDevice(dB, dC);
LaunchST(dA.dPtr(), dB.dPtr(),
         dC.dPtr(), alpha,
         dN: size_t);
DeviceSynchronize();
FromDevice(dA);
Free(dA, dB, dC);
```

Chapel's Array Allocation (n float elements)

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For more details, please see https://ahayashi.github.io/chapel-gpu/index.html

Our GPUIterator module facilitates running GPUAPI programs across CPUs+GPUs

GPUCallBack is a function that includes a sequence of GPUAPI (next slide)

```
forall i in 1..n {
  A(i) = B(i) + alpha * C(i);
}
```

```
forall i in GPU(1..n, GPUCallBack,
                      CPUPercent) {
  A(i) = B(i) + alpha * C(i);
}
```