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GPUAPI: Multi-level Chapel Runtime API for GPUs

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GPUAPI: Multi-level Chapel Runtime API for GPUs

MOTIVATION

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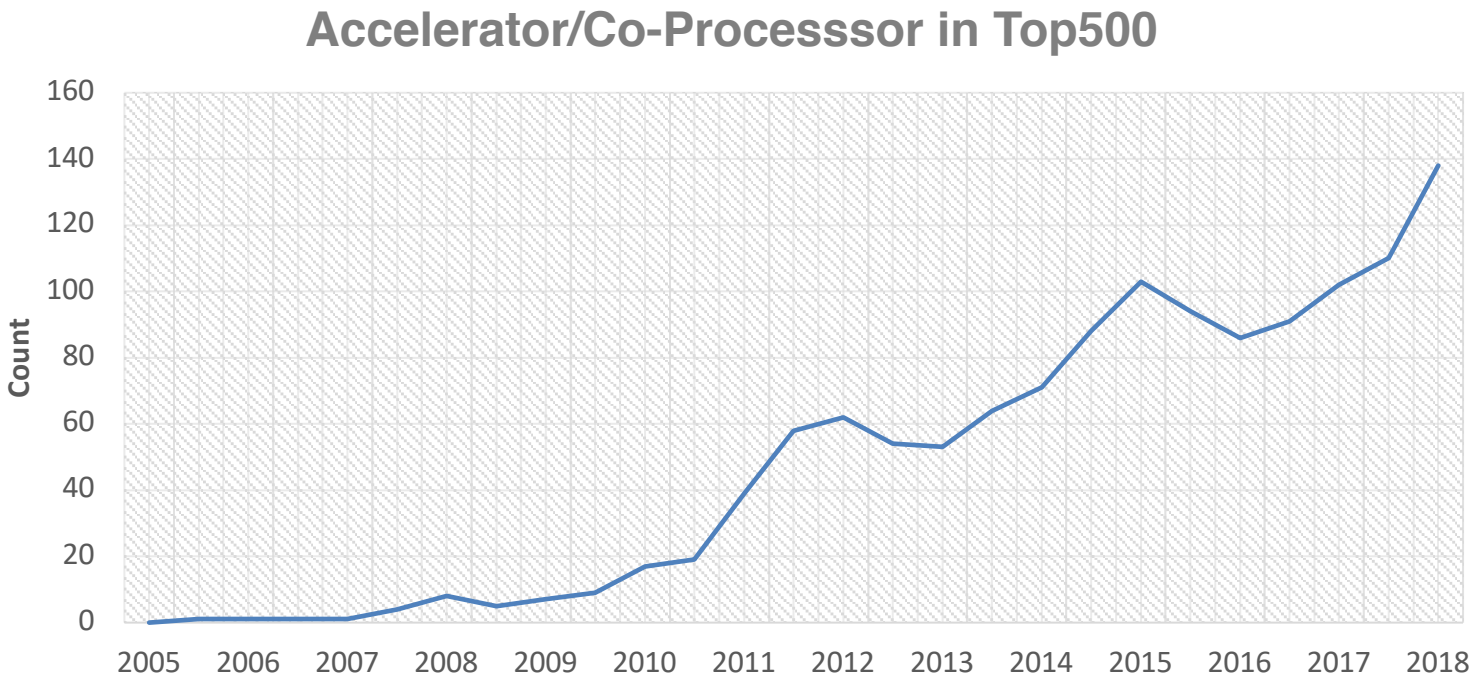
GPUs are “essential” in HPC



All plan to include GPUs!

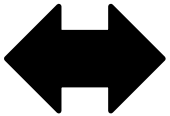
2021-

Source: https://www.top500.org/statistics/list/
Image Sources: ornl.gov, anl.gov, llnl.gov

GPU Programming in Chapel: no “intermediate” programming model

Highest-level Chapel-GPU Programming
(Prototype GPU code generator in Chapel 1.24)

```
1 forall i in 1..n {
2   A(i) = B(i) + alpha * C(i);
3 }
```



A huge gap!

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

```
1  // separate C file
2  __global__ void stream(float *dA, float *dB, float *dC,
3                         float alpha, int N) {
4      int id = blockIdx.x * blockDim.x + threadIdx.x;
5      if (id < N) {
6              dA[id] = dB[id] + alpha * dC[id];
7      }
8  }
9  void GPUST(float *A, float *B, float *C, float alpha,
10            int start, int end, int GPUN) {
11   float *dA, *dB, *dC;
12   CudaSafeCall(cudaMalloc(&dA, sizeof(float) * GPUN));
13   CudaSafeCall(cudaMalloc(&dB, sizeof(float) * GPUN));
14   CudaSafeCall(cudaMalloc(&dC, sizeof(float) * GPUN));
15   CudaSafeCall(cudaMemcpy(dB, B + start, sizeof(float) *
16                           GPUN, cudaMemcpyHostToDevice));
17   CudaSafeCall(cudaMemcpy(dC, C + start, sizeof(float) *
18                           GPUN, cudaMemcpyHostToDevice));
19
20   stream<<<ceil(((float)GPUN)/1024), 1024>>>
21                                  (dA, dB, dC, alpha, GPUN);
22   CudaSafeCall(cudaDeviceSynchronize());
23   CudaSafeCall(cudaMemcpy(A + start, dA, sizeof(float) *
24                           GPUN, cudaMemcpyDeviceToHost));
25   CudaSafeCall(cudaFree(dA));
26   CudaSafeCall(cudaFree(dB));
27   CudaSafeCall(cudaFree(dC));
28 }
```

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

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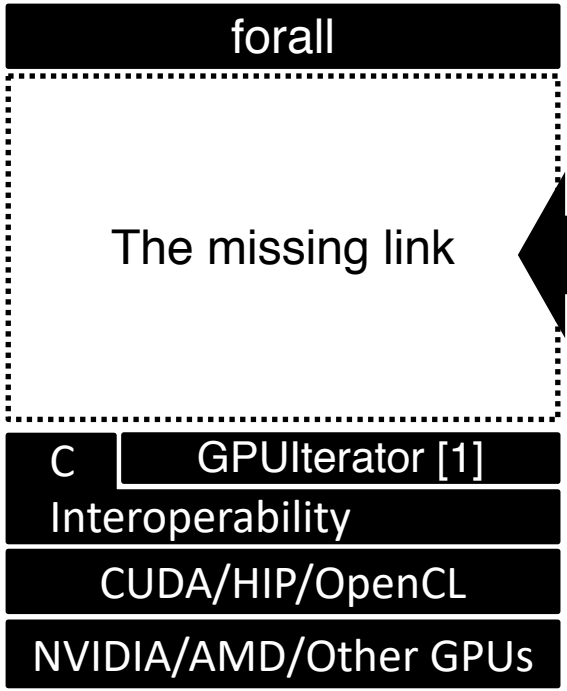
Big Picture: A Multi-level Chapel GPU Programming Model

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

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



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

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

Contributions

- Why Chapel-level 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, …)
- Contributions:
  - Design and implementation of two tiers of Chapel Runtime GPU API
    - ✓ MID-level: Chapel programmer friendly GPU APIs
    - ✓ MID-LOW-level: Thin wrappers for low-level GPU APIs
  - Performance and productivity evaluations on different distributed and single-node platforms using micro benchmark and real-world applications

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GPUAPI: Multi-level Chapel Runtime API for GPUs

DESIGN

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Chapel GPU API Design: Summary

- 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/OpenCL
  - 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
  - Can work with the prototype GPU code generator in Chapel 1.24

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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(…);`

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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`

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

MID-LOW Level

```
1  use GPUAPI;
2  var A: [1..n] real(32);
3  var B: [1..n] real(32);
4  var C: [1..n] real(32);
5  var dA, dB, dC: c_void_ptr;
6  var size: size_t =
7     (A.size:size_t * c_sizeof(A.eltType));
8  Malloc(dA, size);
9  Malloc(dB, size);
10 Malloc(dC, size);
11 Memcpy(dB, c_ptrTo(B), size, TODEVICE);
12 Memcpy(dC, c_ptrTo(C), size, TODEVICE);
13 LaunchST(dA, dB, dC, alpha, N: size_t);
14 DeviceSynchronize();
15 Memcpy(c_ptrTo(A), dA, size, FROMDEVICE);
16 Free(dA); Free(dB); Free(dC);
```

MID-level

```
1  use GPUAPI;
2  var A: [1..n] real(32);
3  var B: [1..n] real(32);
4  var C: [1..n] real(32);
5  var dA = new GPUArray(A);
6  var dB = new GPUArray(B);
7  var dC = new GPUArray(C);
8  toDevice(dB, dC);
9  LaunchST(dA.dPtr(), dB.dPtr(),
10          dC.dPtr(), alpha,
11          dN: size_t);
12 DeviceSynchronize();
13 FromDevice(dA);
14 Free(dA, dB, dC);
```

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

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

```
1
2   var A: [1..n] real(32);
3   var B: [1..n] real(32);
4   var C: [1..n] real(32);
5   var GPUCallBack = lambda (lo: int, hi: int, nElems: int) {
6     var dA = new GPUArray(A);
7     var dB = new GPUArray(B);
8     var dC = new GPUArray(C);
9     toDevice(dB, dC);
10    LaunchST(dA.dPtr(), dB.dPtr(),
11             dC.dPtr(), alpha,
12             dN: size_t);
13    DeviceSynchronize();
14    FromDevice(dA);
15    Free(dA, dB, dC);
16  };
17  forall i in GPU(1..n, GPUCallBack,
18                  CPUPercent) {
19    A(i) = B(i) + alpha * C(i);
20  }
```

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

```
1  // separate C file (CUDA w/ device lambda)
2  void LaunchST(float *dA, float *dB,
3                float *dC, float alpha, int N) {
4    GPU_FUNCTOR(N, 1024, NULL,
5      [=] __device__ (int i) {
6        dA[i] = dB[i] + alpha * dC[i];
7      });
8  }
```

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

```
1  var D: domain(1) dmapped Block(boundingBox={1..n}) = {1..n};
2  var A: [D] real(32);
3  var B: [D] real(32);
4  var C: [D] real(32);
5  var GPUCallBack = lambda (lo: int, hi: int, nElems: int) {
6    var dA = new GPUArray(A.localSlice(lo..hi));
7    var dB = new GPUArray(B.localSlice(lo..hi));
8    var dC = new GPUArray(C.localSlice(lo..hi));
9    toDevice(dB, dC);
10   LaunchST(dA.dPtr(), dB.dPtr(),
11            dC.dPtr(), alpha,
12            dN: size_t);
13   DeviceSynchronize();
14   FromDevice(dA);
15   Free(dA, dB, dC);
16 };
17 forall i in GPU(D, GPUCallBack,
18                 CPUPercent) {
19   A(i) = B(i) + alpha * C(i);
20 }
```

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

```
1  // separate C file (CUDA w/ device lambda)
2  void LaunchST(float *dA, float *dB,
3                float *dC, float alpha, int N) {
4    GPU_FUNCTOR(N, 1024, NULL,
5      [=] __device__ (int i) {
6        dA[i] = dB[i] + alpha * dC[i];
7      });
8  }
```

GPUAPI: Multi-level Chapel Runtime API for GPUs

IMPLEMENTATION

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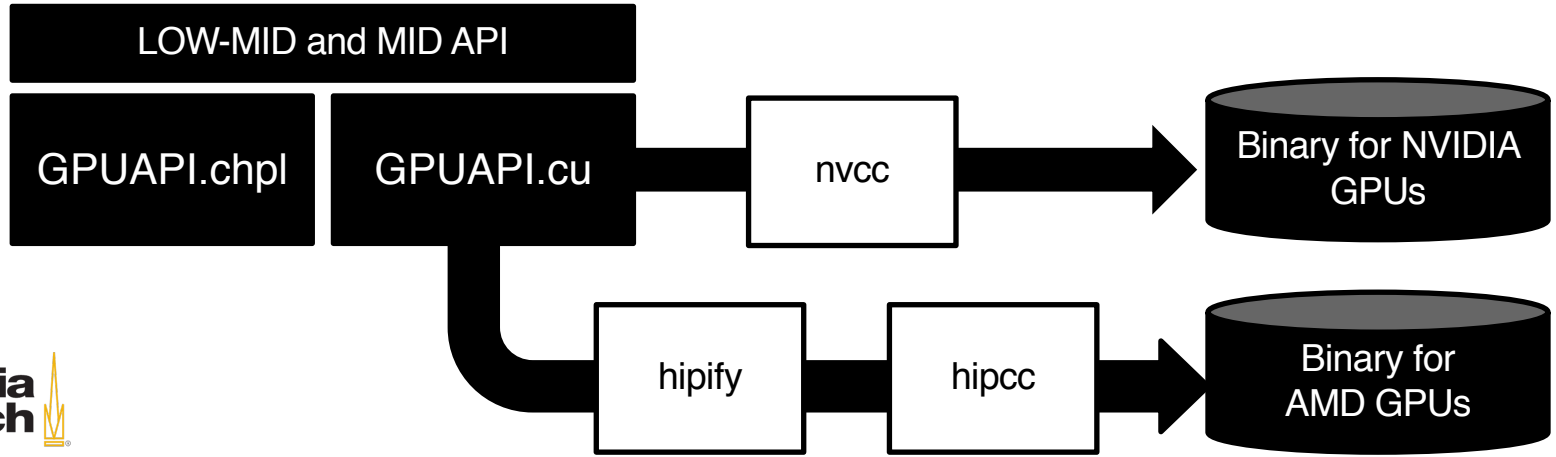
Implementation

- Provides an external module (GPUAPI)
  - Can be used either stand-alone or with the GPUIterator module
  - Provides a cmake-based build system for building GPU-dependent codes
- Currently supports NVIDIA and ROCM-ready AMD GPUs
  - OpenCL is also supported
  - SYCL backend is under development



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PERFORMANCE & PRODUCTIVITY EVALUATIONS

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Performance & Productivity Evaluations

- Platforms
  - Cori GPU@NERSC: Intel Xeon (Skylake) + NVIDIA V100 GPU
  - Summit@ORNL: IBM POWER9 + NVIDIA Tesla V100 GPU
  - A single-node AMD machine: Ryzen9 3900 + Radeon RX570
- Applications
  - Micro-benchmark: STREAM, BlackScholes, Matrix Multiplication, Logistic Regression
  - Real-world applications: Champs, Distributed Exact Optimization
- Chapel Compilers & Options
  - Micro-benchmark: Chapel Compiler 1.20.0 with the --fast option
  - Champs: Chapel Compiler 1.22.0 with the --fast option
  - Distributed exact optimization: 1.24.0 with the --fast option
- GPU Compilers
  - CUDA: NVCC 10.2 (Cori), 10.1 (Summit) with the -O3 option
  - AMD: ROCM 2.9.6, HIPCC 2.8 with the -O3 option

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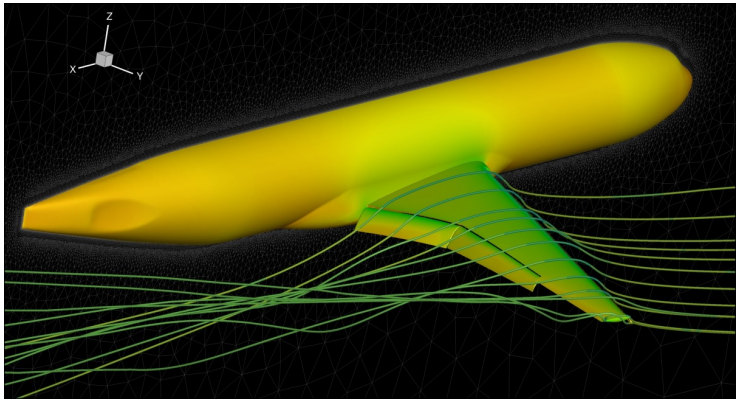
CHAMPS

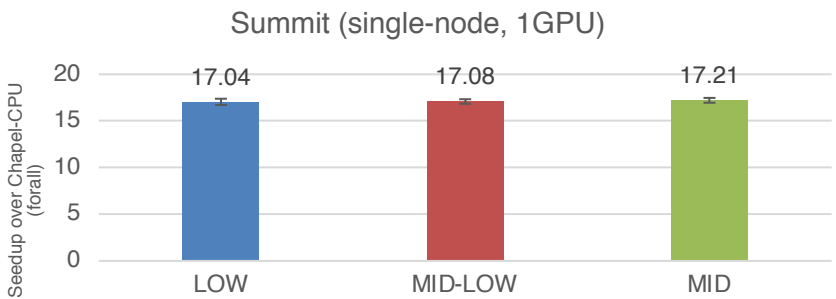


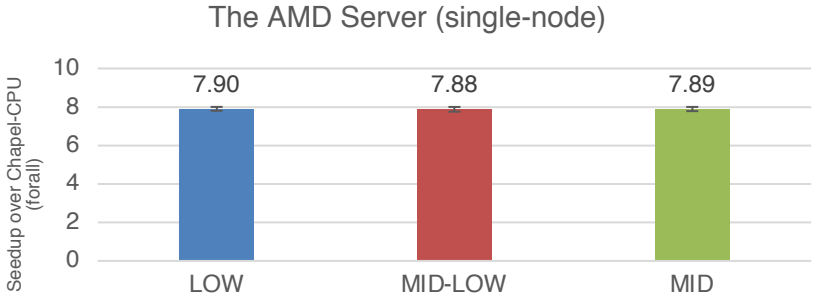
- Summary
  - 3D unstructured finite-volume Reynolds Average Navier-Stokes (RANS) and Potential flow solver using a cell-centered discretization
    - ✓ The potential solver is used
  - Developed at Polytechnique Montreal
  - Originally written entirely in Chapel
    - ✓ We prepared a GPU version of two most time-consuming forall loops
    - ✓ We utilized cuSolver for the solver part

Matthieu Parenteau, Simon Bourgault-Cote, Frédéric Plante, Engin Kayraklioglu, and Eric Laurendeau. "Development of Parallel CFD Applications with the Chapel Programming Language" (AIAA-Scitech 2021 Forum)

Champs (potential solver): Productivity & Performance

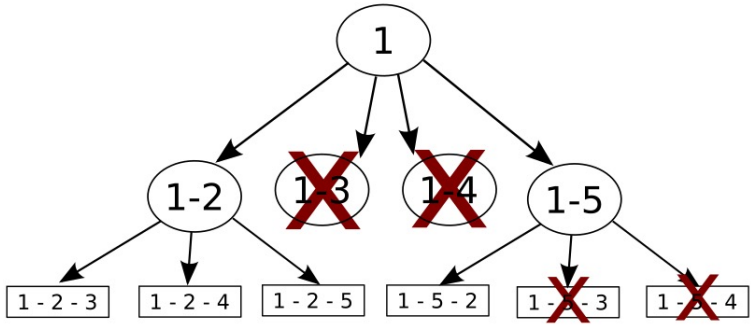
SLOC Added	Chapel	Host (CUDA)	Kernel (CUDA)
LOW	**172**	**117**	361
MID-LOW	**265**	**5**	361
MID	**161**	**5**	361





- Points
  - The use of GPUAPI significantly reduces SLOC for the host part
  - The MID-level API further reduces SLOC for the Chapel part
  - There is no statistically significant performance degradation when GPUAPI is used

Distributed Exact Optimization



- Summary
  - Tree-based exact algorithms: Backtracking, Branch-and-bound
  - Developed at Inria Lille and University of Luxembourg
    - ✓ https://github.com/tcarneirop/ChOp
  - Originally written in Chapel+CUDA (what we call “LOW-level”)
    - ✓ Highly compute-intensive and irregular
    - ✓ We prepared MID and MID-LOW versions

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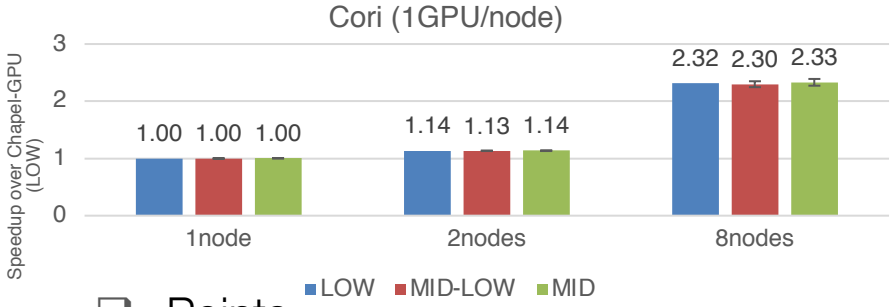
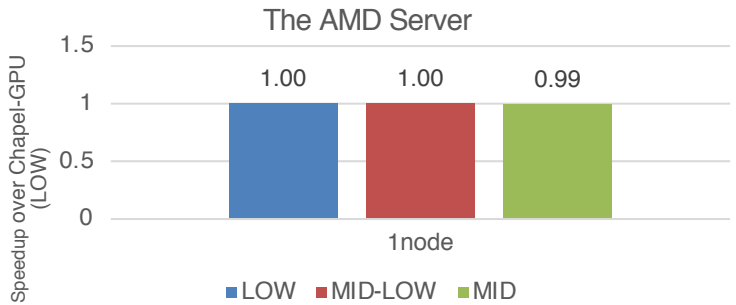
Tiago Carneiro, Nouredine Melab, Akihiro Hayashi, Vivek Sarkar,
“Towards Chapel-based Exascale TreeSearch Algorithms: dealing with multiple GPU accelerators” (HPCS2020)

Distributed Exact Optimization: Productivity & Performance

SLOC Added	Chapel	Host (CUDA)	Kernel (CUDA)
LOW	**2**	**16**	71
MID-LOW	**13**	**4**	71
MID	**9**	**4**	71





- Points
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  - The MID-level API further reduces SLOC for the Chapel part
  - There is no statistically significant performance degradation when GPUAPI is used

GPUAPI: Multi-level Chapel Runtime API for GPUs

CONCLUSIONS

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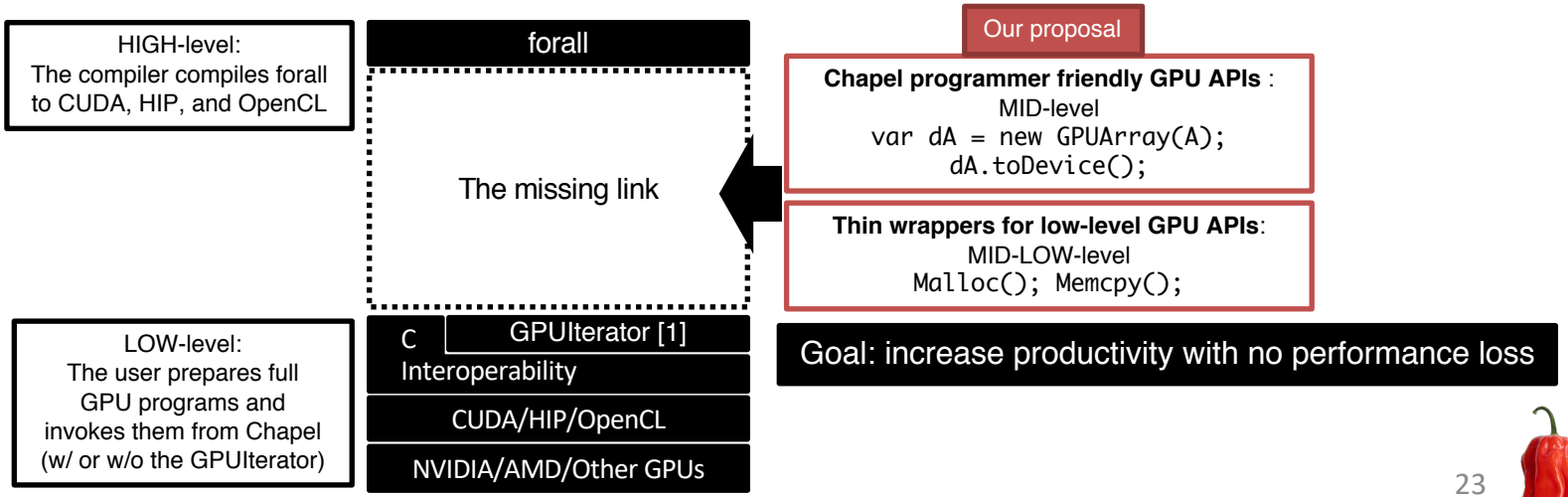
Conclusions

- Introduced multi-level GPUAPI for Chapel
  - Improves both productivity and portability
  - Verified with microbenchmark and real-world applications
  - Verified on Summit@ORNL, Cori-GPU@NERSC, and an AMD server



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which is supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.

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Join our community

- GPUAPI+GPUIterator 0.3 is released!
  - The repository
    - ✓ https://github.com/ahayashi/chapel-gpu
  - Detailed Documents
    - ✓ https://ahayashi.github.io/chapel-gpu/index.html
- Our community is growing!

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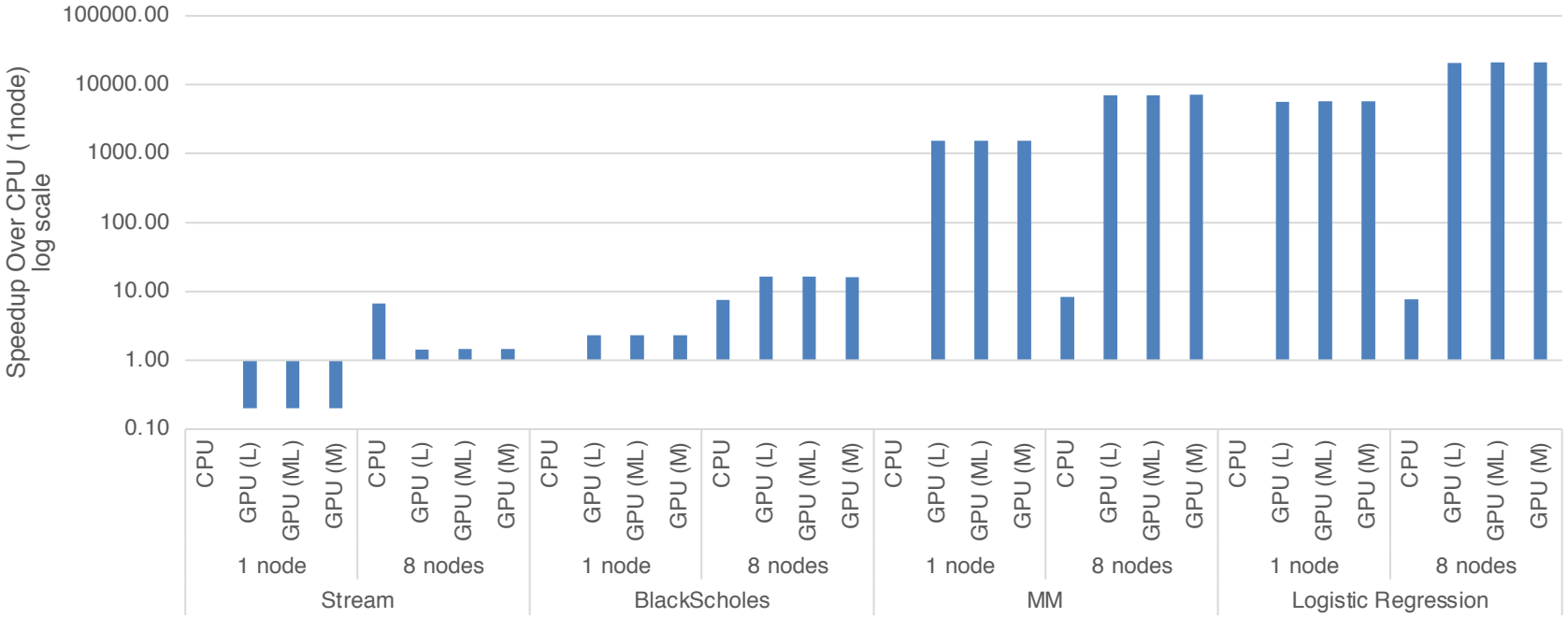
BACKUP SLIDES

Micro-benchmark Performance (Cori)



Micro-benchmark Performance (Summit)