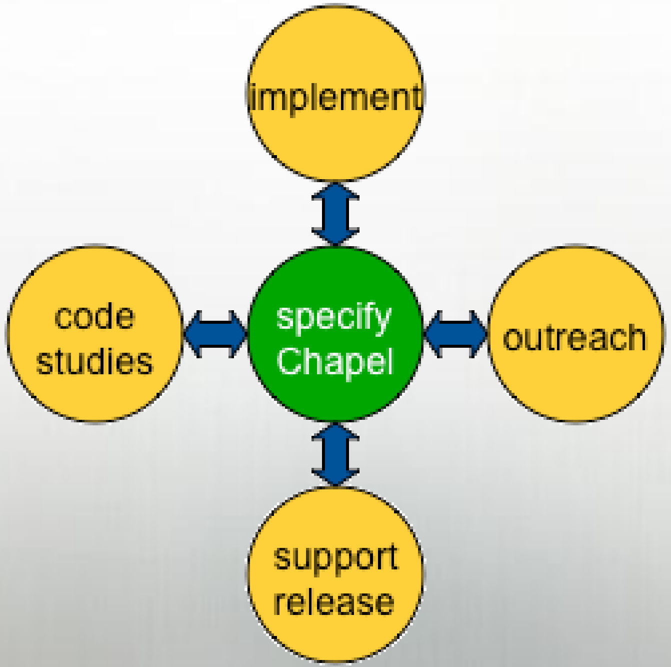
Chapel: Project Overview

Outline

- What we do
- Project Status
- Who we are
- Collaboration Sidebar: Chapel on CPU+GPU

Chapel Work

- Chapel Team's Focus:
  - specify Chapel syntax and semantics
  - implement open-source prototype compiler for Chapel
  - perform code studies of benchmarks, apps, and libraries in Chapel
  - do community outreach to inform and learn from users/researchers
  - support collaborators and users of code releases
  - refine language based on all these activities



Implementation Status -- Version 1.2.0

In a nutshell:

- Most features work at a functional level
- Many performance optimizations remain

This is a good time to:

- Try out the language
- Give us feedback to improve the language
- Use Chapel for parallel programming education
- Use Chapel for non-performance-critical projects

In evaluating the language:

- Try to judge it by how it should *ultimately* perform rather than how it does today
    - lots of low-hanging fruit remains, as well as some challenges

Chapel and Education

- If I were teaching parallel programming, I'd want to cover:
  - data parallelism
  - task parallelism
  - concurrency
  - synchronization
  - locality/affinity
  - deadlock, livelock, and other pitfalls
  - performance tuning
  - …
- I don't think there's a good language out there…
  - for teaching *all* of these things
  - for teaching some of these things well at all
  - ***until now:*** I think Chapel has the potential to play a crucial role here

“I Like Chapel, how can I help?”

- Let people know that you like it and why
  - your colleagues
  - your employer/institution
  - Cray leadership (stop by the Cray booth this week)
- Help us evolve it from prototype to production
  - our team’s size is OK for creating and prototyping, but too small to create a product-grade version in a timely manner
    - contribute back to the source base
    - collaborate with us
    - help fund us to grow the team
    - help move us from “How will Cray make Chapel succeed?” to “How can we as a community make Chapel succeed?”

Join Our Team

- Cray:

Brad Chamberlain

Sung-Eun Choi

Greg Titus

Lee Prokowich

Vass Litvinov

●●●

- External Collaborators:

Albert Sidelnik

Jonathan Turner

Srinivas Sridharan

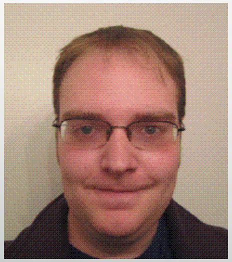
●●●

You?

- Interns:

Jonathan Claridge

Hannah Hemmaplardh


Andy Stone

Jim Dinan

Rob Bocchino

Mack Joyner

●●●

We Are Hiring

Currently:

- Software Engineer (Compiler Developer)
- Manager

Upcoming:

- R&D on Targeting next-generation nodes
  - GPUs, tiled architectures, scratchpad memories, manycore, …

Select Collaborations

- **Notre Dame/ORNL** (Peter Kogge, Srinivas Sridharan, Jeff Vetter): Asynchronous software transactional memory over distributed memory
- **UIUC** (David Padua, Albert Sidelnik, Maria Garzarán): CPU-GPU computing
- **BSC/UPC** (Alex Duran): Chapel over Nanos++ user-level tasking
- **Argonne** (Rusty Lusk, Rajeev Thakur, Pavan Balaji): Chapel over MPICH
- **Sandia** (Rich Murphy, Kyle Wheeler): Chapel over Qthreads user threading
- **UT Austin** (Calvin Lin, Karthik Murthy): Memory consistency models
- **CU Boulder** (Jeremy Siek, Jonathan Turner): Interfaces, concepts, generics
- **U. Oregon/Paratools Inc.** (Sameer Shende): Performance analysis with Tau
- **U. Malaga** (Rafa Asenio, Maria Gonzales, Rafael Larossa): Parallel file I/O
- **PNNL/CASS-MT** (John Feo, Daniel Chavarria): Cray XMT tuning
- (your name here?)

Collaboration Ideas (see chapel.cray.com for more details)

- memory management policies/mechanisms
- dynamic load balancing: task throttling and stealing
- parallel I/O and checkpointing
- exceptions; resiliency
- language interoperability
- application studies and performance optimizations
- index/subdomain semantics and optimizations
- targeting different back-ends (LLVM, MS CLR, …)
- runtime compilation
- library support
- tools: debuggers, performance analysis, IDEs, interpreters, visualizers
- database-style programming
- (your ideas here…)

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- (your name here?)

Targeting GPGPUs With Chapel

Albert Sidelnik, María J. Garzarán, David Padua (UIUC)

Brad Chamberlain (Cray Inc.)

Motivating Example: HPCC Stream Triad

```
A = scalar * B + C;
```

HPCC STREAM Triad

```
config const m = 1000, tbSizeX = 256;

const alpha = 3.0;

const ProbDist = new dmap(new dist(GPUDist(rank=1, tbSizeX)));

const ProbSpace: domain(1) dmapped ProbDist = [1..m];

var A, B, C: [ProbSpace] real;


forall (a,b,c) in (A,B,C) do
  a = b + alpha * c;
```

New configuration constant to specify # threads per block

Distribution to target a GPU

Loops and arrays using this domain are implemented on the GPU

No changes required to the computation for other architectures

Case Study: STREAM (current practice)

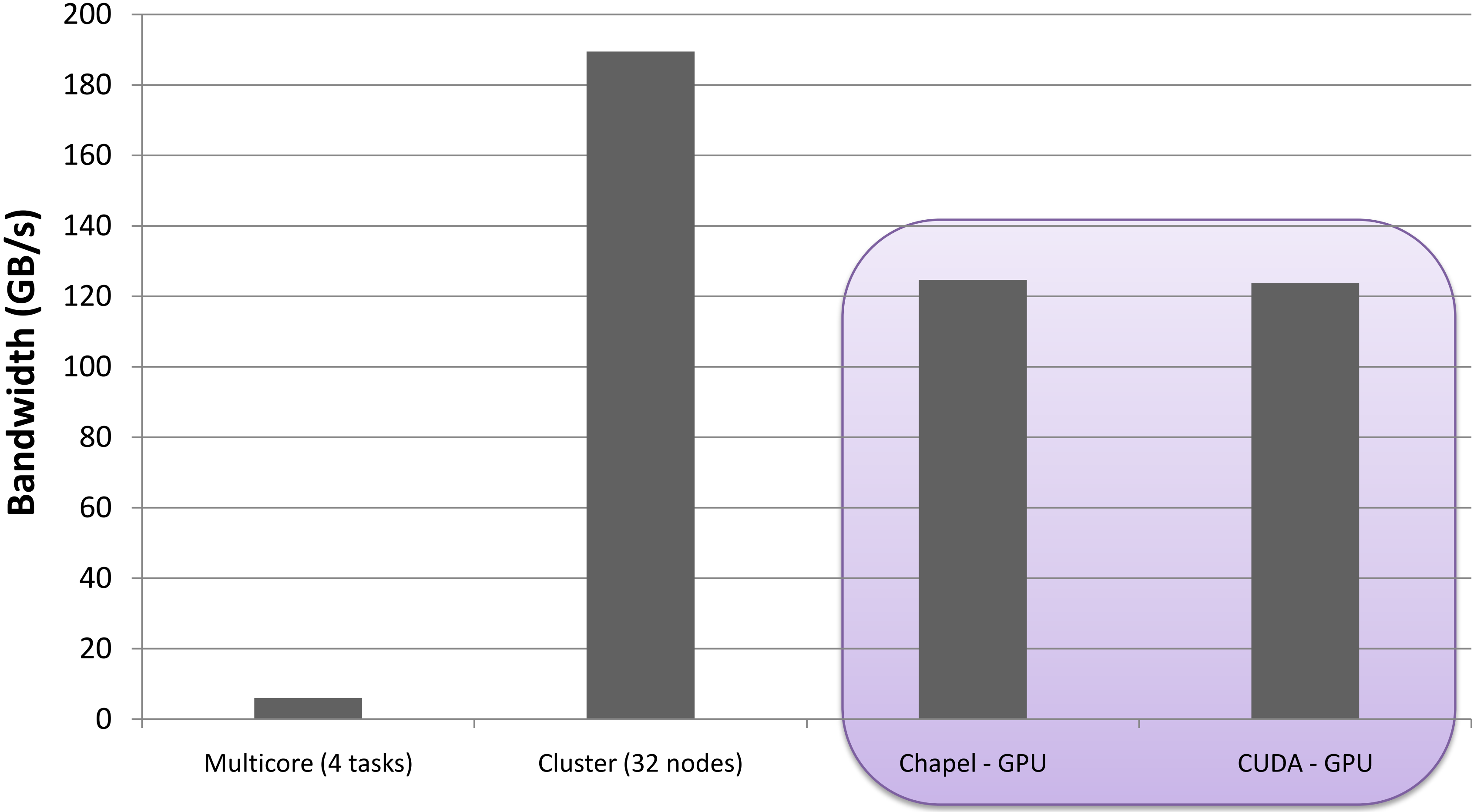
CUDA

```
#define N        2000000

int main() {
  float *d_a, *d_b, *d_c;
  float scalar;

  cudaMalloc((void**)&d_a, sizeof(float)*N);
  cudaMalloc((void**)&d_b, sizeof(float)*N);
  cudaMalloc((void**)&d_c, sizeof(float)*N);

  dim3 dimBlock(128);
  dim3 dimGrid(N/dimBlock.x );
  if( N % dimBlock.x != 0 ) dimGrid.x+=1;

  set_array<<<dimGrid,dimBlock>>>(d_b, .5f, N);
  set_array<<<dimGrid,dimBlock>>>(d_c, .5f, N);

  scalar=3.0f;
  STREAM_Triad<<<dimGrid,dimBlock>>>(d_b, d_c, d_a, scalar, N);
  cudaThreadSynchronize();

  cudaFree(d_a);
  cudaFree(d_b);
  cudaFree(d_c);
}

__global__ void set_array(float *a,  float value, int len) {
  int idx = threadIdx.x + blockIdx.x * blockDim.x;
  if (idx < len) a[idx] = value;
}

__global__ void STREAM_Triad( float *a, float *b, float *c,
                              float scalar, int len) {
  int idx = threadIdx.x + blockIdx.x * blockDim.x;
  if (idx < len) c[idx] = a[idx]+scalar*b[idx];
}
```

MPI + OpenMP

```
#include <hpcc.h>
#ifdef _OPENMP
#include <omp.h>
#endif

static int VectorSize;
static double *a, *b, *c;

int HPCC_StarStream(HPCC_Params *params) {
  int myRank, commSize;
  int rv, errCount;
  MPI_Comm comm = MPI_COMM_WORLD;

  MPI_Comm_size( comm, &commSize );
  MPI_Comm_rank( comm, &myRank );

  rv = HPCC_Stream( params, 0 == myRank);
  MPI_Reduce( &rv, &errCount, 1, MPI_INT, MPI_SUM, 0, comm );

  return errCount;
}

int HPCC_Stream(HPCC_Params *params, int doIO) {
  register int j;
  double  scalar;

  VectorSize = HPCC_LocalVectorSize( params, 3, sizeof(double), 0 );

  a = HPCC_XMALLOC( double, VectorSize );
  b = HPCC_XMALLOC( double, VectorSize );
  c = HPCC_XMALLOC( double, VectorSize );

  if (!a || !b || !c) {
    if (c) HPCC_free(c);
    if (b) HPCC_free(b);
    if (a) HPCC_free(a);
    if (doIO) {
      fprintf( outFile, "Failed to allocate memory (%d).\n", VectorSize );
      fclose( outFile );
    }
    return 1;
  }

#ifdef _OPENMP
#pragma omp parallel for
#endif
  for (j=0; j<VectorSize; j++) {
    b[j] = 2.0;
    c[j] = 0.0;
  }

  scalar = 3.0;

#ifdef _OPENMP
#pragma omp parallel for
#endif
  for (j=0; j<VectorSize; j++)
    a[j] = b[j]+scalar*c[j];

  HPCC_free(c);
  HPCC_free(b);
  HPCC_free(a);

  return 0;
}
```

Performance of STREAM
Multicore vs. Cluster vs. GPU



For STREAM, the Chapel and CUDA implementations match perform

Leveraging Chapel for GPUs

Leveraging the Language

- Chapel has support for user-defined distributions
  - Recipe for mapping data and computation onto the device
  - Implemented in Chapel source code
  - More flexible than HPL and ZPL's distributions
- Arrays used on the accelerator are declared using the GPU distribution and domain

```
const ProbDist = new dmap(dist(GPUDist(rank=1, tbSizeX)));
const ProbSpace: domain(1) dmapped ProbDist = [1..m];
var A : [ProbSpace] real;
```

- Depend on `forall` as the main support for data-parallelism on a device

```
forall I in ProbSpace do
  A(I) = …
```

Leveraging the Language (cont.)

- Low-level support for different memory spaces including shared and constant
- Support for both explicit and implicit data transfers between the host and device
  - Implicit data transfers depend on compiler support
  - Based on simple data-flow analysis
- Ongoing work to support whole-array operations
  - E.g. `A = B + scalar * C`;
- Support for reduction/scan operations executed on the GPU

Another Example

Coulombic Potential (CP) from Parboil Benchmark Suite

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
                                         tbSizeY=BLOCKSIZEY));
const space : domain(2) dmapped gdst = volmemsz_dom;
var energygrid : [space] = 0.0;
const constgdst = new dmap(new GPUConstDist(rank=1));
const atomspace : domain(1) dmapped constgdst = [1..MAXATOMS];

/* initialize atominfo from input file */
var atominfo : [atomspace] float4 = ...;
forall (xindex,yindex) in space {
   var energyval = 0.0;
   var (coorx,coory) = (gspacing*xindex, gspacing*yindex);
   for atom in atominfo {
         var (dx,dy) = (coorx-atom.x, coory-atom.y);
         var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
         energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
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const constgdst = new dmap(new GPUConstDist(rank=1));
const atomspace : domain(1) [illegible] MAXATOMS];

/* initialize atominfo from input file */
var atominfo : [atomspace] float4 = ...;
forall (xindex,yindex) in space {
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   for atom in atominfo {
        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Main GPU distribution used

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
                                          tbSizeY=BLOCKSIZEY));
const space : domain(2) dmapped gdst = volmemsz_dom;
var energygrid : [space] = 0.0;
const constgdst = new dmap(new GPUConstDist(rank=1));
const atomspace : domain(1) dmapped constgdst = [1..MAXATOMS];

/* initia
var atominfo : [atomspace] float4 = ...;
forall (xindex,yindex) in space {
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        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Domains created using GPU distribution

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
                                         tbSizeY=BLOCKSIZEY));
const space : domain(2) dmapped gdst = volmemsz_dom;
var energygrid : [space] = 0.0;
const constgdst = new dmap(new GPUConstDist(rank=1));
const atomspace : domain(1) dmapped constgdst = [1..MAXATOMS];

/* initi
var atom
forall (xindex,yindex) in space {
   var energyval = 0.0;
   var (coorx,coory) = (gspacing*xindex, gspacing*yindex);
   for atom in atominfo {
        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Allocate GPU memory and initialize to 0.0

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
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/* initialize atominfo from input file */
var atom
forall (
   var energyval = 0.0;
   var (coorx,coory) = (gspacing*xindex, gspacing*yindex);
   for atom in atominfo {
        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Constant memory GPU distribution and associated domain used to hold atoms

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
                                         tbSizeY=BLOCKSIZEY));
const space : domain(2) dmapped gdst = volmemsz_dom;
var energygrid : [space] = 0.0;
const constgdst = new dmap(new GPUConstDist(rank=1));
const atomspace : domain(1) dmapped constgdst = [1..MAXATOMS];

/* initialize atominfo from input file */
var atominfo : [atomspace] float4 = ...;
forall (xindex,yindex) in space {
   var energyval = 0.0;
   var                                  gspacing*yindex);
   for
        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```

Allocate GPU Constant memory

Another Example - Coulombic Potential

```
const volmemsz_dom = [1..VOLSIZEY,1..VOLSIZEX];
const gdst = new dmap(new GPUDist(rank=2,tbSizeX=BLOCKSIZEX,
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   for atom in atominfo {
        var (dx,dy) = (coorx-atom.x, coory-atom.y);
        var r_1 = 1.0 / sqrt(dx*dx + dy*dy + atom.z);
        energyval += atom.w * r_1;
   }
   energygrid(yindex, xindex) += energyval;
}
```
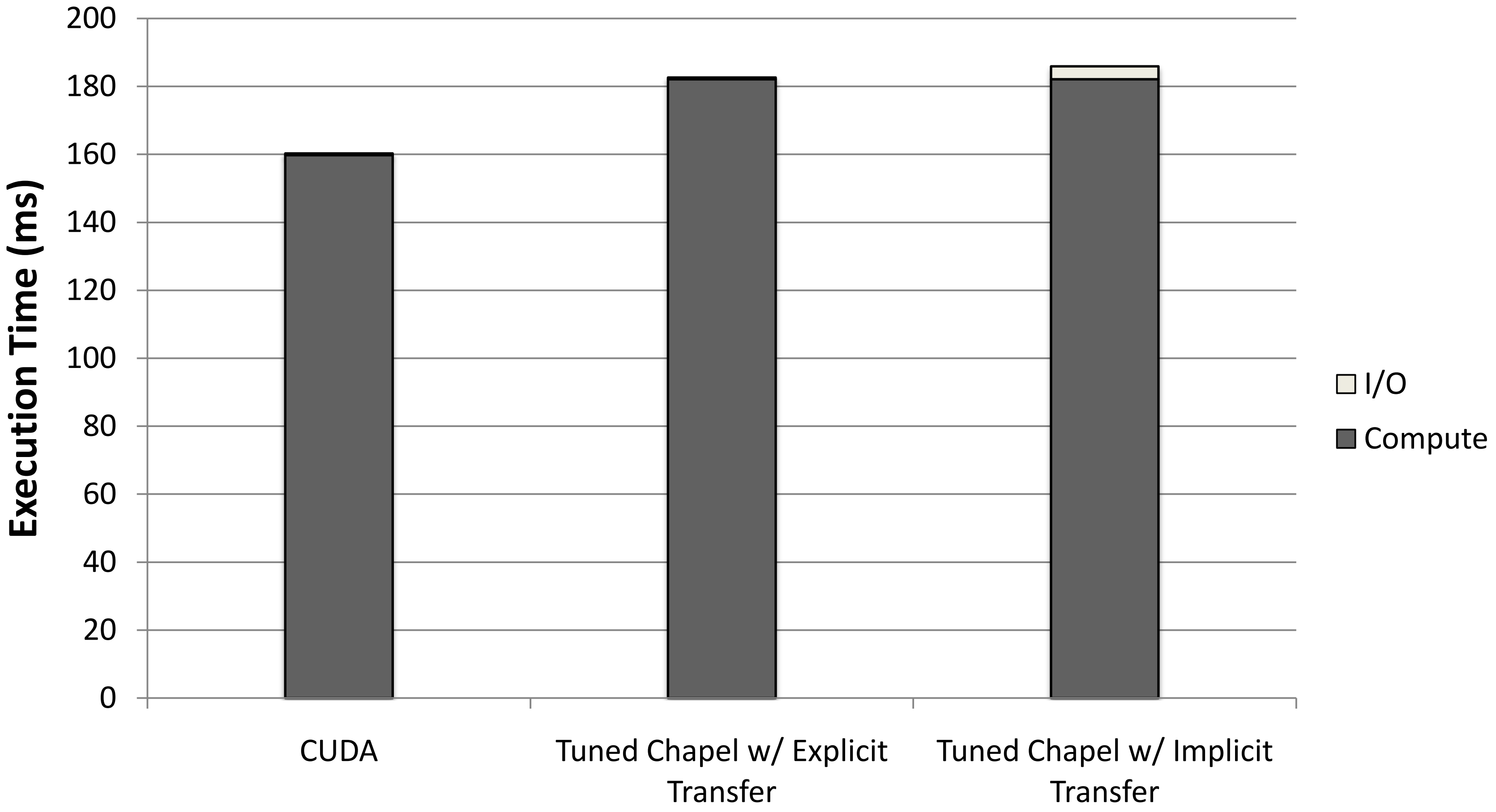

The main kernel

Coulombic Potential (CP)
(Nvidia GTX 280 GPU)



Chapel Team's Next Steps

- Expand our set of supported distributions
- Continue to improve performance
- Continue to add missing features
- Expand the set of codes that we are studying
- Expand the set of architectures that we are targeting
- Support the public release
- Continue to support collaborations and seek out new ones
- Continue to expand our team

Questions?

- What we do
- Project Status
- Who we are
- Collaboration Sidebar: Chapel on CPU+GPU