Hewlett Packard
Enterprise

APPLICATION EXAMPLES OF LEVERAGING TASK PARALLELISM WITH CHAPEL

Michelle Mills Strout with slides from Brad Chamberlain, Ben Albrecht, Elliot Ronaghan, Brandon Neth, and Scott Bachman

WAMTA: Workshop on Asynchronous Many-Task Systems and Applications
February 15, 2023

CURRENT CHAPEL DEVELOPMENT TEAM AT HPE

- **Lead**:
  - Michelle Strout
- **Tech Lead:**
  - Brad Chamberlain
- **Manager**:
  - Tim Zinsky
- **Subteam leads**:
  - Michael Ferguson
  - Elliot Ronaghan
  - Engin Kayraklioglu
  - Lydia Duncan
- **BTR/DevOps**:
  - Bhavani Jayakumaran
- **Visiting Scholar from NCAR:**
  - Scott Bachman

Developers:

Ahmad Rezaii
Andy Stone
Anna Rift
Ben Harshbarger
Ben McDonald
Daniel Fedorin
David Iten
David Longnecker
Jade Abraham
Jeremiah Corrado
John Hartman
Vass Litvinov

CHAPEL PROGRAMMING LANGUAGE

Chapel is a general-purpose programming language that provides

ease of parallel programming,

high performance, and

portability, enabling development on **laptops** and execution on **supercomputers**.

Some history

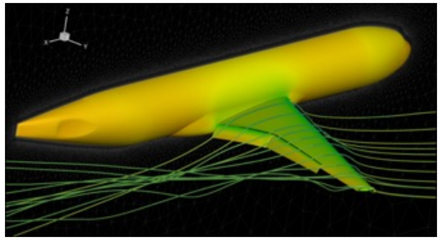
2002: Design and development **started** with DARPA HPCS program,

2002-now: core development team continuously funded and grown from 5 to 21 FTEs,

2019: Arkouda data analytics package written in Chapel by others to provide interactive supercomputing (https://github.com/Bears-R-Us/arkouda), and

2019-now: Arkouda being used in production, and CHAMPs, ChplUltra, and ChOp being actively developed and used to do research.

HOW APPLICATIONS ARE USING CHAPEL

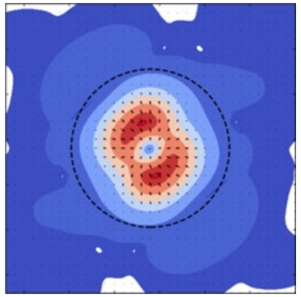


Rewrite existing codes into Chapel (~100K lines of Chapel)

CHAMPS: 3D Unstructured CFD

Éric Laurendeau, Simon Bourgault-Côté, Matthieu Parenteau, et al.

École Polytechnique Montréal



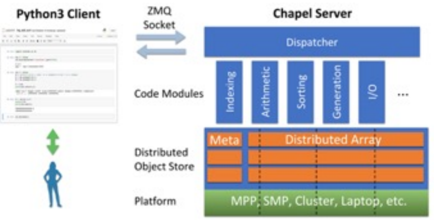
Writing code in Chapel

(~10k lines of including parallel FFT)

ChplUltra: Simulating Ultralight Dark Matter

Nikhil Padmanabhan, J. Luna Zagorac, *et al.*

Yale University / University of Auckland

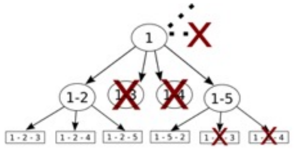


Chapel server for a Python client (~30K lines of Chapel)

Arkouda: NumPy at Massive Scale

Mike Merrill, Bill Reus, et al.

US DoD



Calling out to Cuda

(~1k lines of Chapel)

ChOp: Chapel-based Optimization

Tiago Carneiro, Nouredine Melab, *et al.*

INRIA Lille, France

MOTIVATION: APPS WRITTEN IN CHAPEL ARE FAST AND SCALABLE

Arkouda data analytics framework

- Sorting is within 2-3x of the world record
- Loading an HDF5 file, gather, scatter, and stream are all significantly faster than with Dask
- Arkouda can do groupby and argsort, which Dask can't

CHAMPS Aeronautics Code

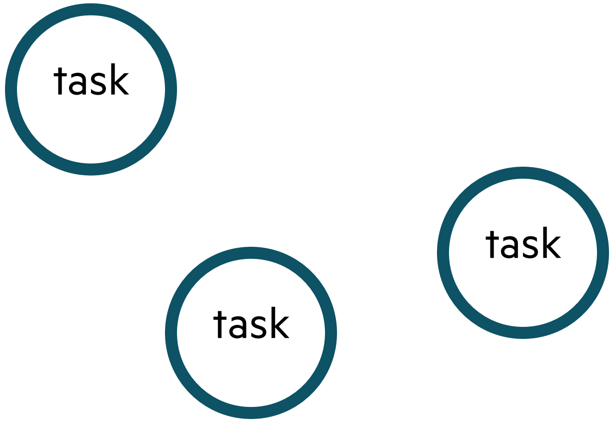
- performance and scalability competitive with MPI + C++
- CHAMPS scales up to 256 nodes/locales on Cray XC. That experiment had 640 million cells in a 3D grid

Coral Reef Diversity Image Analysis

- Computation in Matlab took days, Chapel version with some algorithmic improvements takes seconds

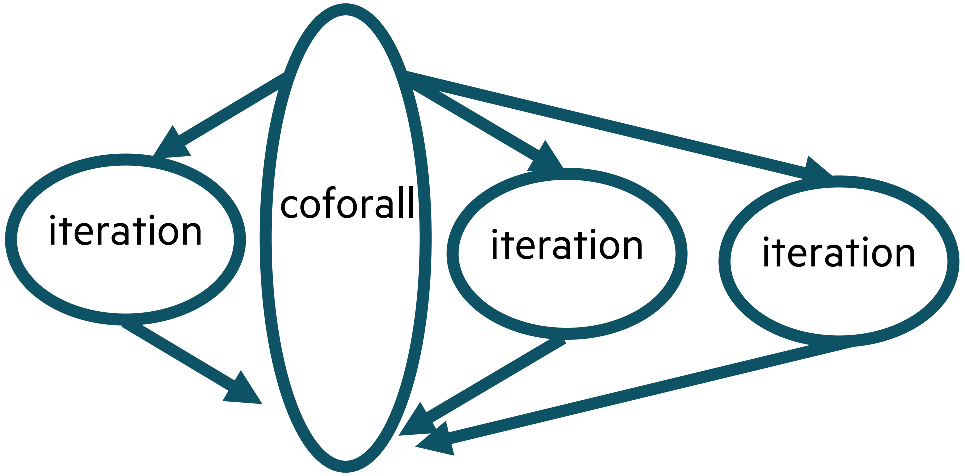
TASKS IN CHAPEL

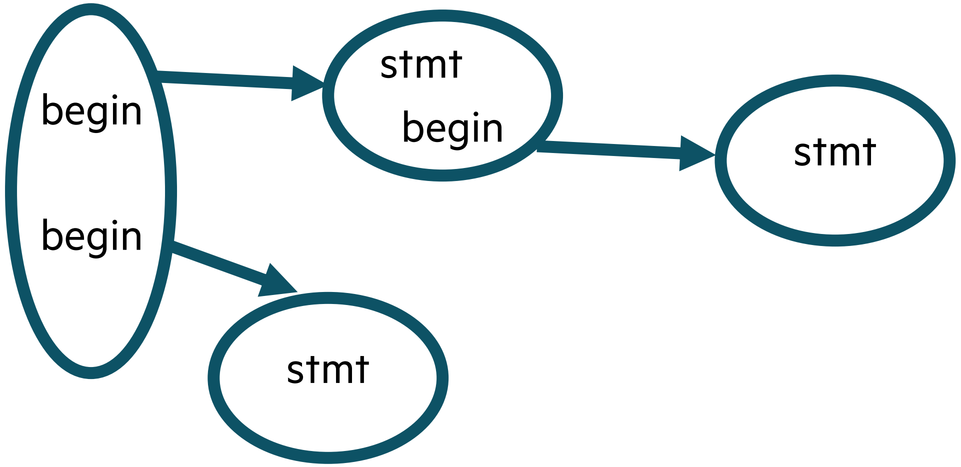
- A ***task*** is a unit of computation that can and should be executed in parallel with other tasks
- Tasks can **share data** with other tasks through the lexical scoping of variables in the program's global namespace
- The **mapping** of tasks to nodes is done either
  - by the programmer **explicitly** by using the concept of locales or
  - **implicitly** through the 'forall' data parallelism abstraction when iterating over distributed data structures
    - 'forall' is explicit mapped to locales under the hood
    - can be user-defined with an iterator
- Tasks can execute indefinitely until they yield control explicitly or through synchronization constructs



TASK PARALLELISM SUPPORTED BY CHAPEL

- **Synchronous parallelism**
  - 'coforall', distributed memory parallelism across processes/locales with 'on' syntax
  - 'coforall', shared-memory parallelism over threads
  - 'cobegin', executes all statements in block in parallel
- **Asynchronous parallelism**
  - 'begin', creates an asynchronous task
  - 'sync' and 'atomic' vars for task coordination
  - spawning subprocesses
- **Higher-level parallelism abstractions**
  - 'forall', data parallelism and iterator abstraction
  - 'foreach', SIMD parallelism
  - 'scan', operations such as cumulative sums
  - 'reduce', operations such as summation





USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

- "Hello world", shared and distributed-memory parallel: **'coforall'**
- HPO, HyperParameter Optimization for ML training: **subprocess spawning**
- Arkouda, data analytics package: '**coforall', 'scan', 'forall'**
- CHAMPS, 3D computational fluid dynamics for airplanes: **'coforall'**
- ChOp, Chapel-based Optimization: **'forall', 'coforall', 'begin', 'atomic'**
- ParFlow, C+MPI hydrodynamics code calling out to Chapel: **'forall'**
- Coral reef, image analysis for eco diversity: **'coforall', 'forall', 'cobegin'**
- Arbitrary task graphs: **'begin', 'atomic'**

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

When poll is active, respond at **pollev.com/michellestrout402**

Which kind of task parallelism interests you the most?

- ‘coforall' for distributed-memory parallelism
- ‘coforall' for shared-memory parallelism
- ‘cobegin’ for executing statements in parallel
- ‘begin’ for asynchronous parallelism
- ‘forall’ abstraction

Start the presentation to see live content. For screen share software, share the entire screen. Get help at **pollev.com/app**

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

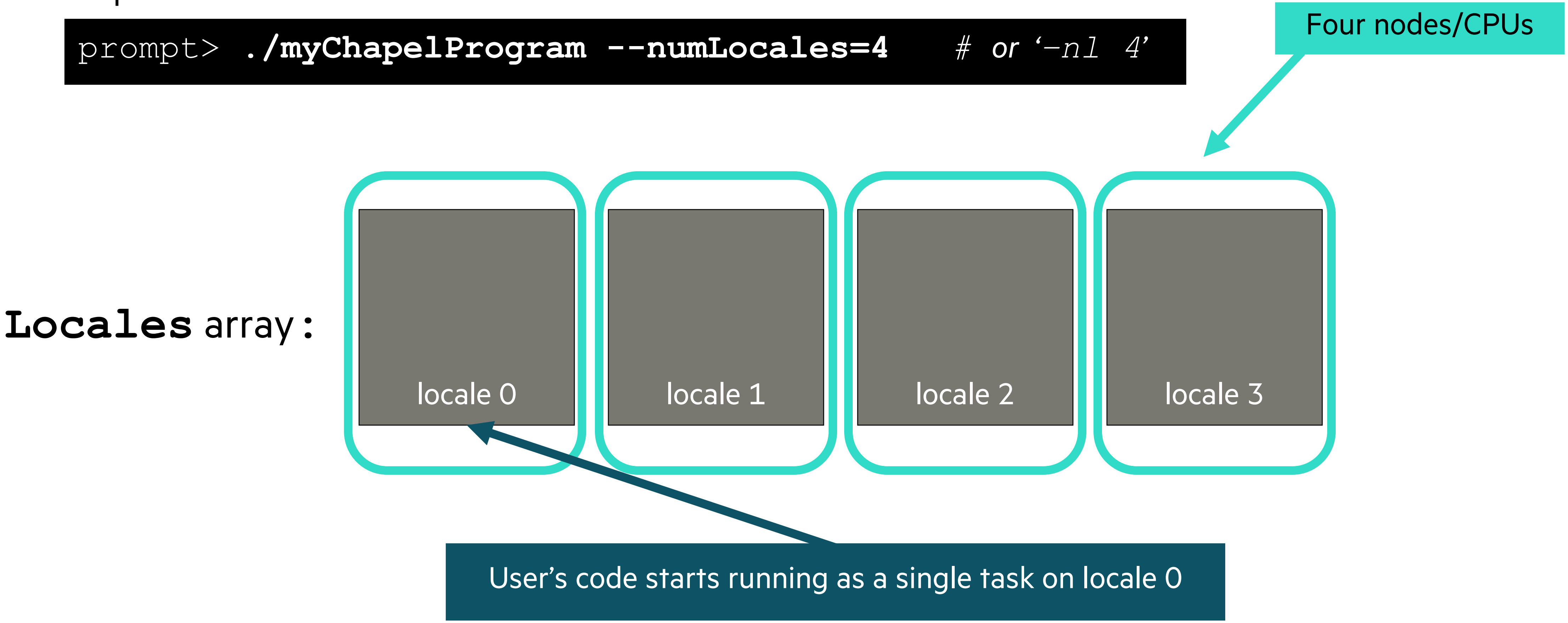
Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

CHAPEL EXECUTION MODEL AND TERMINOLOGY: LOCALES

- Locales can run tasks and store variables
  - Think "compute node" on a parallel system
  - User specifies number of locales on executable's command-line

```
prompt> ./myChapelProgram --numLocales=4    # or '-nl 4'
```



Four nodes/CPUs

User's code starts running as a single task on locale 0

TASK-PARALLEL "HELLO WORLD"

helloTaskPar.chpl

```
const numTasks = here.numPUs();
coforall tid in 1..numTasks do
  writef("Hello from task %n of %n on %s\n",
         tid, numTasks, here.name);
```

TASK-PARALLEL “HELLO WORLD”

helloTaskPar.chpl

```
const numTasks = here.numPUs();
coforall tid in 1..numTasks do
  writef("Hello from task %n of %n on %s\n",
         tid, numTasks, here.name);
```

‘here’ refers to the locale on which we’re currently running

how many processing units (think “cores”) does my locale have?

what’s my locale’s name?

TASK-PARALLEL “HELLO WORLD”

helloTaskPar.chpl

```
const numTasks = here.numPUs();
coforall tid in 1..numTasks do
  writef("Hello from task %n of %n on %s\n",
         tid, numTasks, here.name);
```

a 'coforall' loop executes each iteration as an independent task

```
prompt> chpl helloTaskPar.chpl
prompt> ./helloTaskPar
Hello from task 1 of 4 on n1032
Hello from task 4 of 4 on n1032
Hello from task 3 of 4 on n1032
Hello from task 2 of 4 on n1032
```

TASK-PARALLEL "HELLO WORLD"

helloTaskPar.chpl

```
const numTasks = here.numPUs();
coforall tid in 1..numTasks do
  writef("Hello from task %n of %n on %s\n",
         tid, numTasks, here.name);
```

```
prompt> chpl helloTaskPar.chpl
prompt> ./helloTaskPar
Hello from task 1 of 4 on n1032
Hello from task 4 of 4 on n1032
Hello from task 3 of 4 on n1032
Hello from task 2 of 4 on n1032
```

So far, this is a shared-memory program

Nothing refers to remote locales,
explicitly or implicitly

TASK-PARALLEL “HELLO WORLD” (DISTRIBUTED VERSION)

helloTaskPar.chpl

```
coforall loc in Locales {
  on loc {
    const numTasks = here.numPUs();
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n on %s\n",
             tid, numTasks, here.name);
  }
}
```

TASK-PARALLEL “HELLO WORLD” (DISTRIBUTED VERSION)

helloTaskPar.chpl

```
coforall loc in Locales {
  on loc {
    const numTasks = here.numPUs();
    coforall tid in 1..numTasks do
      writef("Hello from task %n of %n on %s\n",
             tid, numTasks, here.name);
  }
}
```

create a task per locale
on which the program is running

have each task run ‘on’ its locale

then print a message per core,
as before

```
prompt> chpl helloTaskPar.chpl
prompt> ./helloTaskPar -nl=4
Hello from task 1 of 4 on n1032
Hello from task 4 of 4 on n1032
Hello from task 1 of 4 on n1034
Hello from task 2 of 4 on n1032
Hello from task 1 of 4 on n1033
Hello from task 3 of 4 on n1034
Hello from task 1 of 4 on n1035
…
```

'coforall' has what semantics?

Starts an asynchronous task for each iteration

Starts a task for each iteration and waits until they all complete

Groups iterations so there is a task per available thread

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

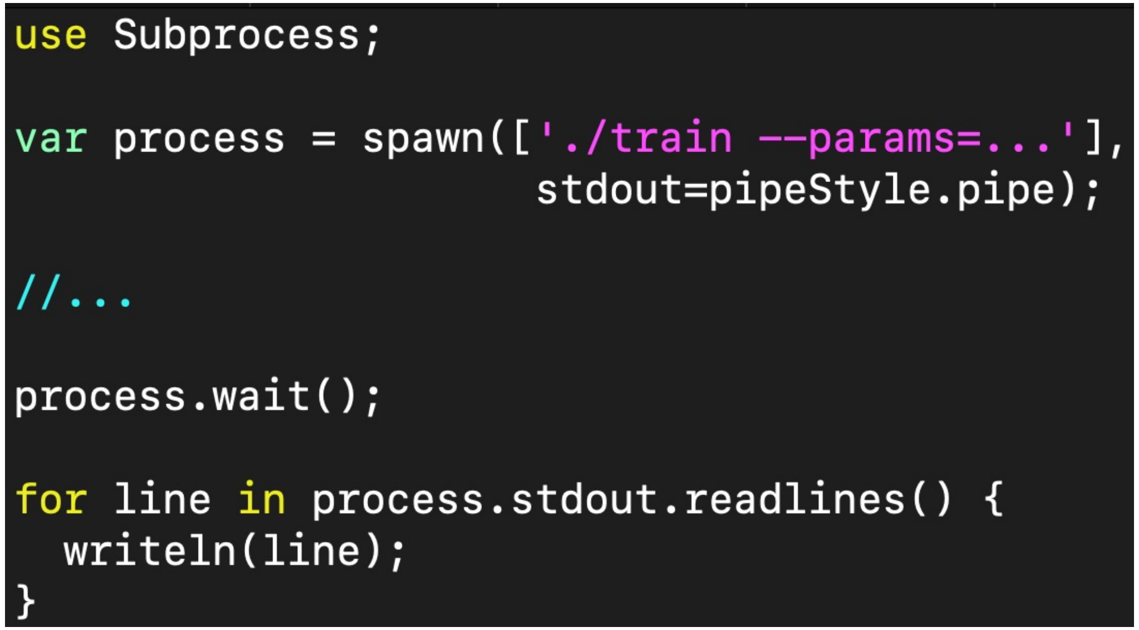
There will be fun questions throughout the talk

CRAY HYPERPARAMETER OPTIMIZATION (HPO)

- Python interface and Chapel backend

- Supported distributed optimization as well as distributed training
  - E.g., 20 nodes, 5 HPO instances each training on 4 nodes

- Chapel code includes spawning subprocesses, which is a non-blocking operation
  - Blocking on the completion of the subprocess can be done with a 'wait'



```
use Subprocess;

var process = spawn(['./train --params=...'],
                     stdout=pipeStyle.pipe);

//...

process.wait();

for line in process.stdout.readlines() {
  writeln(line);
}
```

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

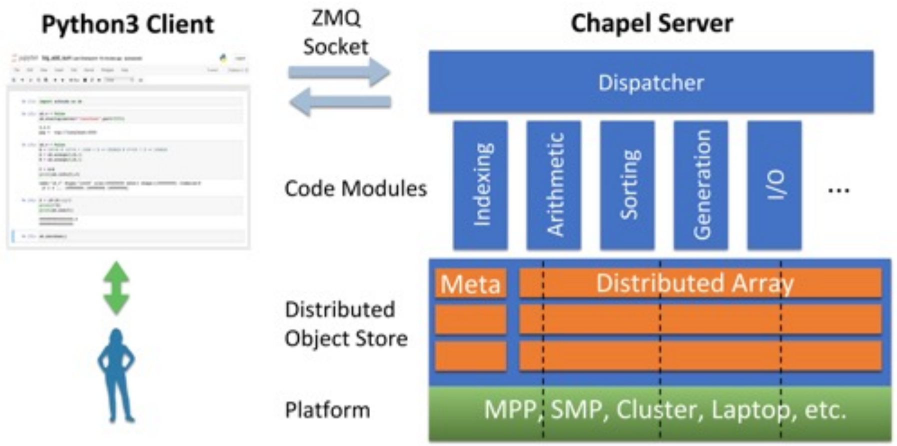
ARKOUDA IN ONE SLIDE

What is it?

- A Python library supporting a key subset of NumPy and Pandas for Data Science
- Implemented using a client-server model with Chapel as the server to support scalability
- Designed to compute results within the human thought loop (seconds to minutes on TB-scale arrays)
- ~30K lines of Chapel

Who did it?

- Mike Merrill, Bill Reus, et al., US DOD
- Open-source: https://github.com/Bears-R-Us/arkouda

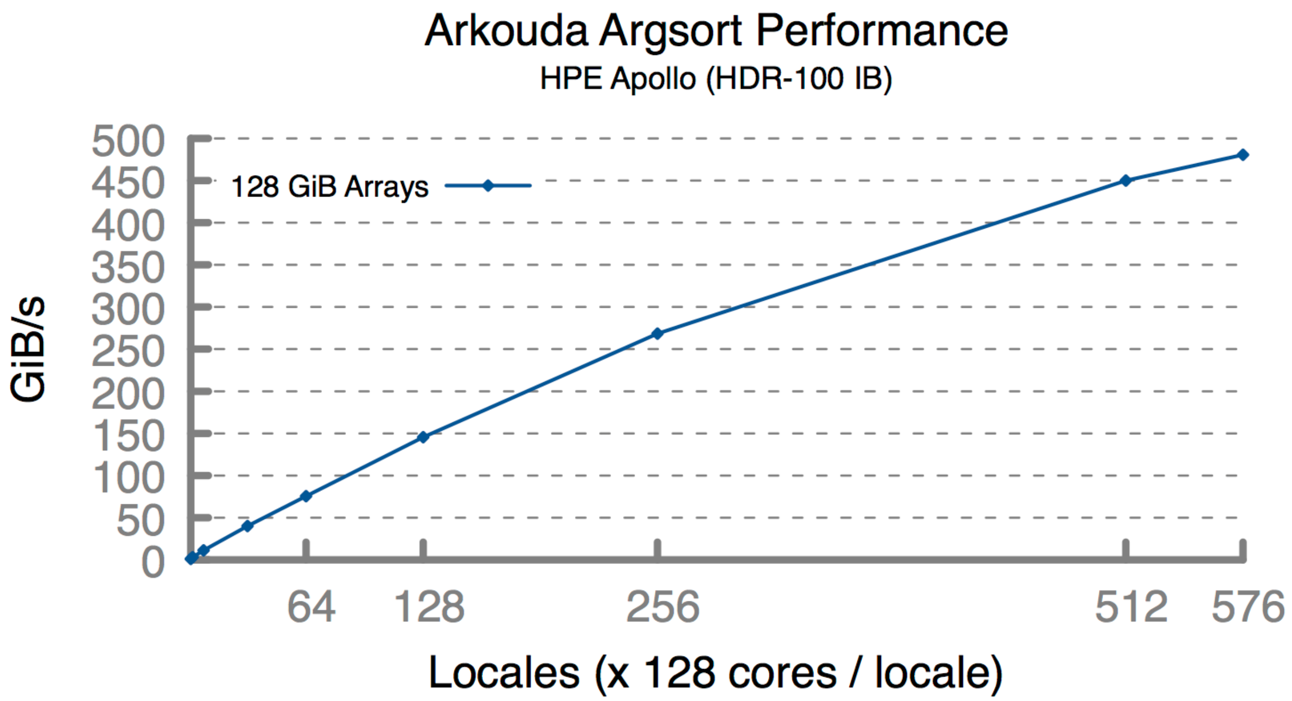


Why Chapel?

- high-level language with C-comparable performance
- great distributed array support
- ports from laptop to supercomputer
- close to Pythonic—thus is readable for Python users who look under the hood

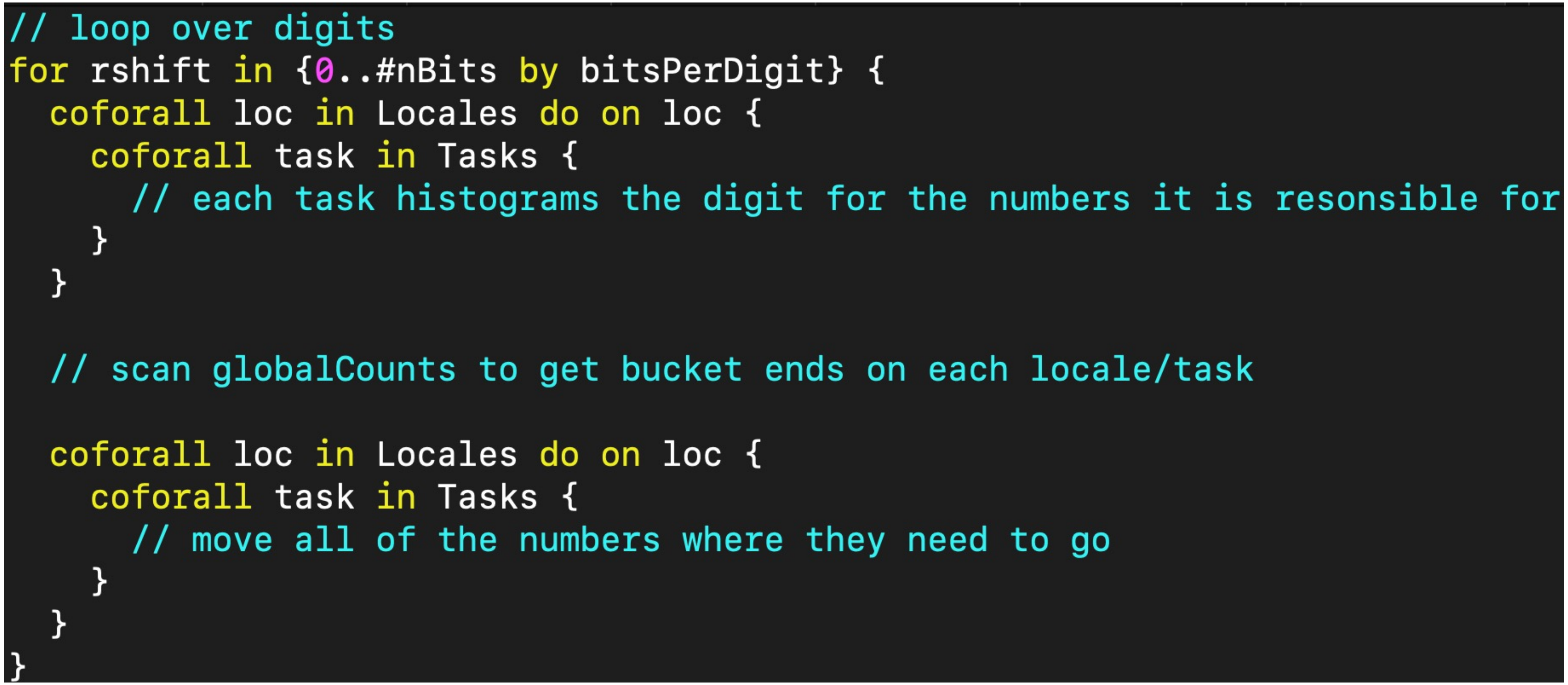
ARKOUDA ARGSORT: HERO RUN

- Recent hero run performed on large Apollo system
  - 72 TiB of 8-byte values
  - 480 GiB/s (2.5 minutes elapsed time)
  - used 73,728 cores of AMD Rome
  - ~100 lines of Chapel code
- Believed to be within 2-3x of world record
  - however, a bit apples-to-oranges:
    - they sort larger key values (to their benefit)
    - their data starts on disk (SSD)



PARALLEL PATTERNS IN ARKOUDA

- Lots of 'forall' used over distributed arrays
- Superfast radix sort uses 'coforall' and 'scan'



```
// loop over digits
for rshift in {0..#nBits by bitsPerDigit} {
  coforall loc in Locales do on loc {
    coforall task in Tasks {
      // each task histograms the digit for the numbers it is resonsible for
    }
  }

  // scan globalCounts to get bucket ends on each locale/task

  coforall loc in Locales do on loc {
    coforall task in Tasks {
      // move all of the numbers where they need to go
    }
  }
}
```

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

CHAMPS IN ONE SLIDE

What is it?

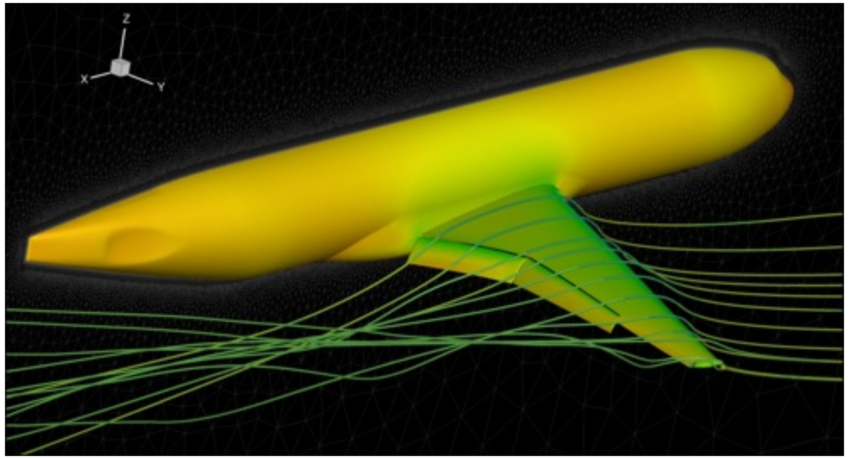
- Computational Fluid Dynamics framework for airplane simulation written from scratch
- Modular design, permitting various computational modules to be integrated (or not)
- First ~48k lines written in ~2 years, now up to over 100k lines

Who did it?

- Professor Eric Laurendeau’s team at Polytechnique Montreal
- not open-source (yet), but available by request to researchers

Task Parallel Patterns

- SPMD-like parallelism with 'coforall's
- Threaded parallelism with 'coforall's



CHAMPS: QUOTE AND STATUS FROM THE PI

- Eric Laurendeau (PI) gave our CHIUW 2021 keynote
  - title: *HPC Lessons From 30 Years of Practice in CFD Towards Aircraft Design and Analysis*
  - students also gave talks on their individual efforts
  - key excerpt:

    "So CHAMPS, that's the new solver that has been made, and all made by the students… So, [Chapel] promotes the programming efficiency. It was easy for them to learn. …I see the end result. We ask students at the master's degree to do stuff that would take 2 years and they do it in 3 months. And I'm not joking, this is from 2 years to 3 months. So if you want to take a summer internship and you say 'program a new turbulance model', well they manage. And before, it was impossible to do."

- CHAMPS participating in 4th CFD High Lift Prediction Workshop and 1st Icing Prediction Workshop
  - teams compete against one another to do the same massive simulations
    - entries compared in terms of model accuracy, performance, practicality
  - sponsored by AIAA and NASA
  - initial results are looking competitive to longer-lived / more established codes from Stanford, MIT, etc.

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

CHOP IN ONE SLIDE

What is it?

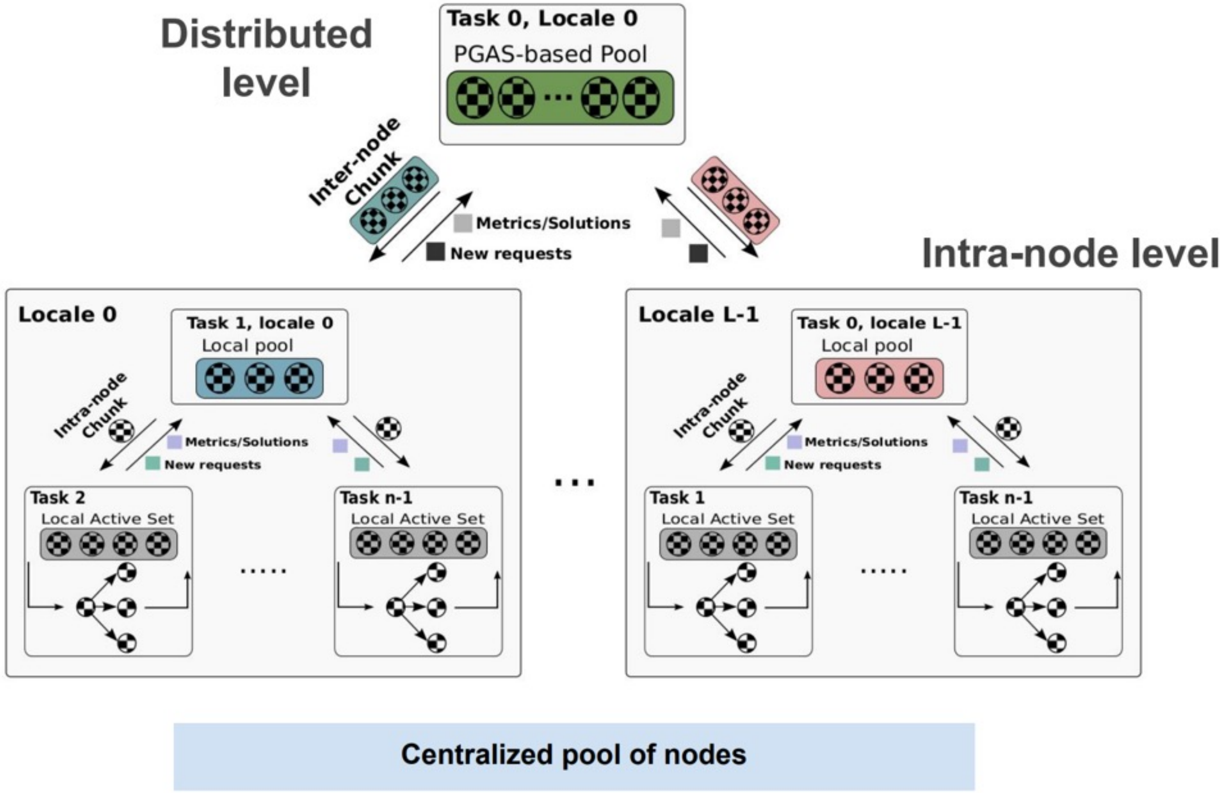
- Tree-based, branch and bound optimization algorithms
- irregular tree, lots of pruning

Who did it?

- Tiago Carneiro and Nouredine Melab at the Imec - Belgium and INRIA Lille
- Open-source: https://github.com/tcarneirop/ChOp

Chapel Task Parallel Constructs

- Heavy use of 'forall' to implement a distributed task load balancer
- Using 'begin' and 'atomic' variables in checkpointing code



from slides for "Towards Ultra-scale Optimization Using Chapel" by Tiago Carneiro (University of Luxembourg) and Nouredine Melab (INRIA Lille), CHIUW 2021

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

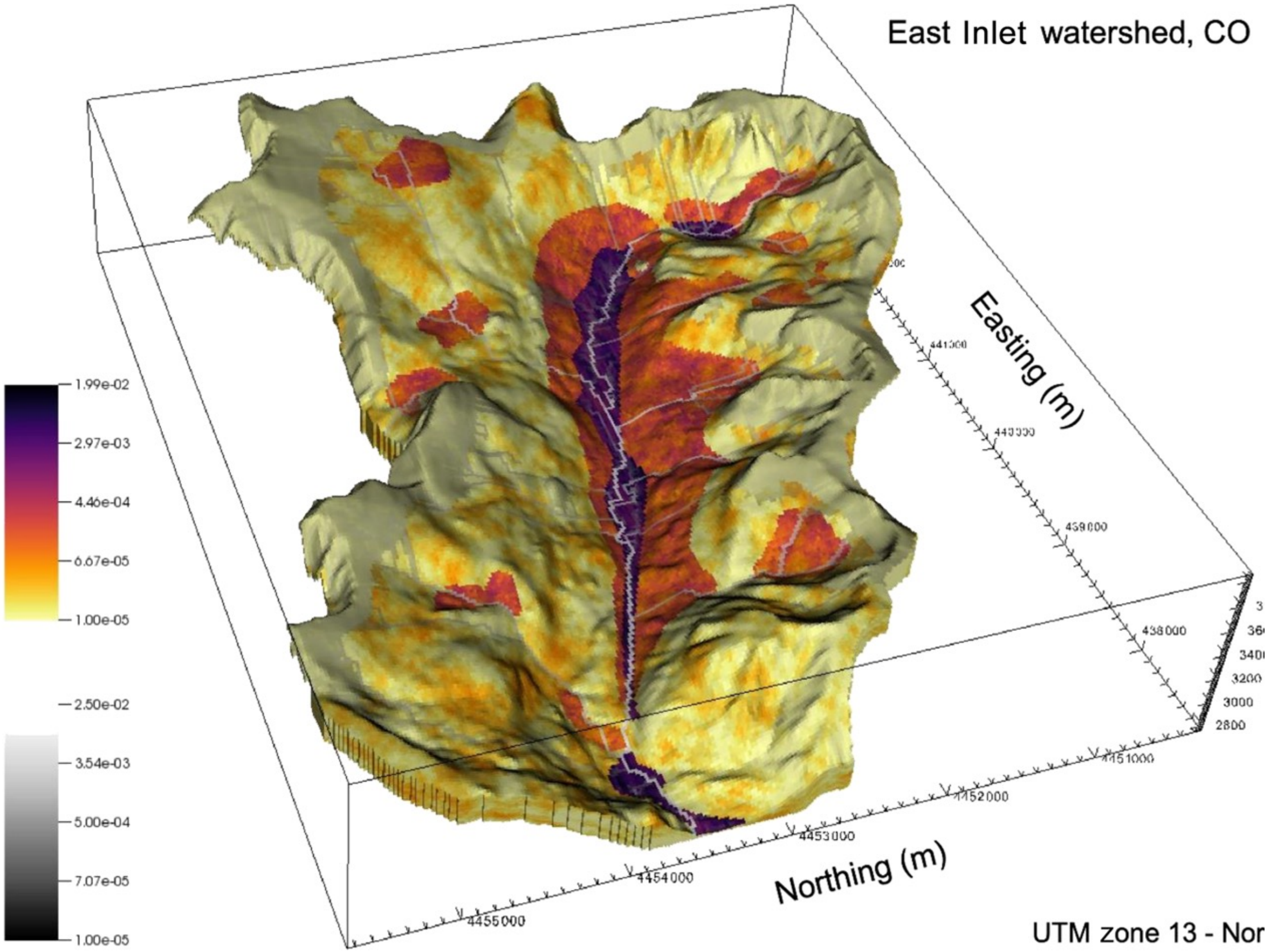
Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

PARFLOW

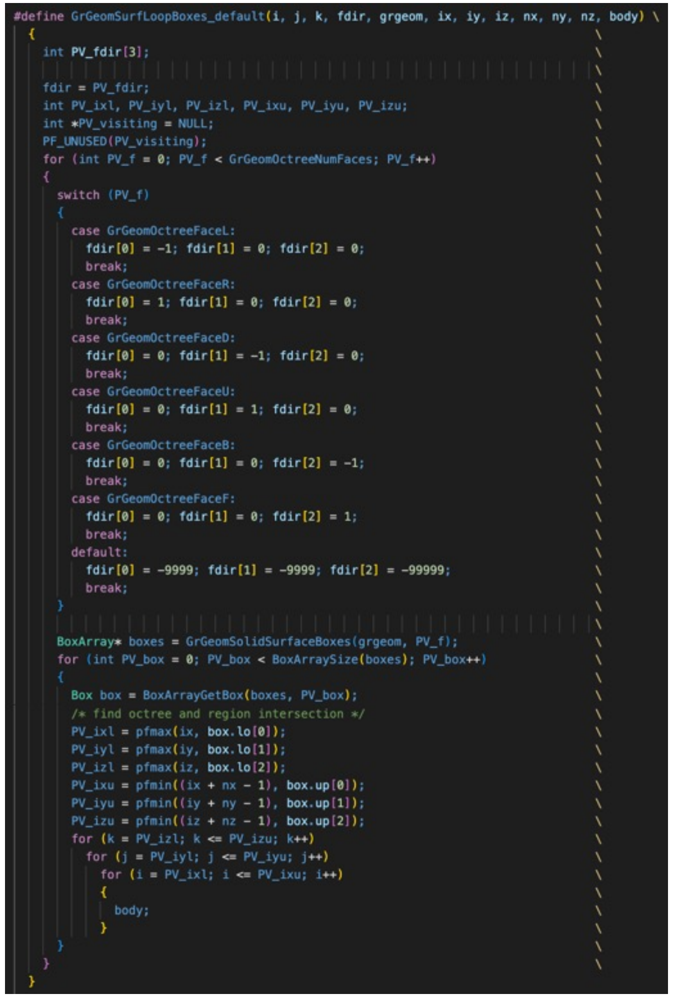
- Watershed hydrology model
- Bottom of the bedrock to the top of the canopy
- Began in 1998
- > 1,000,000 lines of C code

- **Chapel piece**
  - Summer intern project
  - MPI+C code calls out to Chapel
  - Uses 'forall' for …
    - Shared-memory parallelism
    - User-defined iterators over boundary conditions



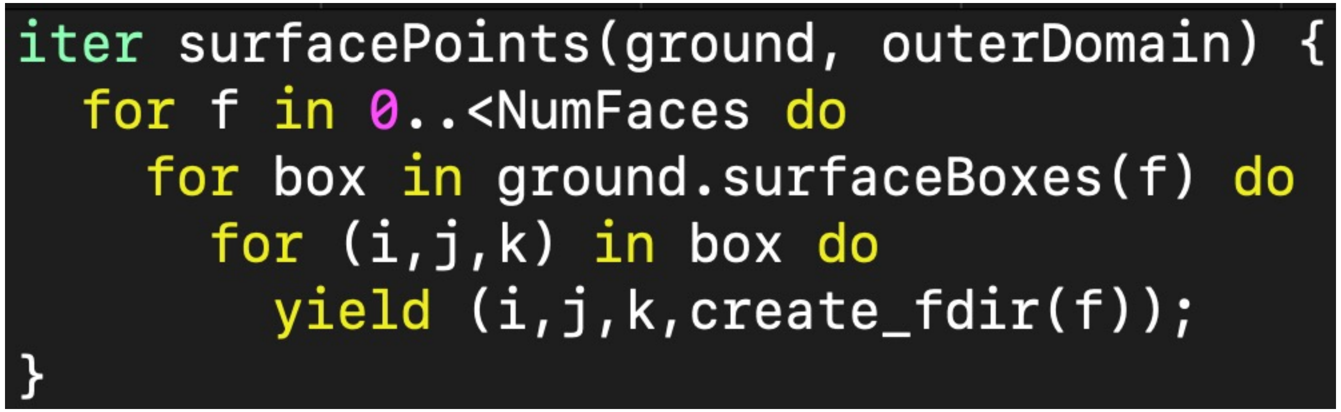
SURFACE TRAVERSAL, C VS CHAPEL

Surface Traversal Macro, C



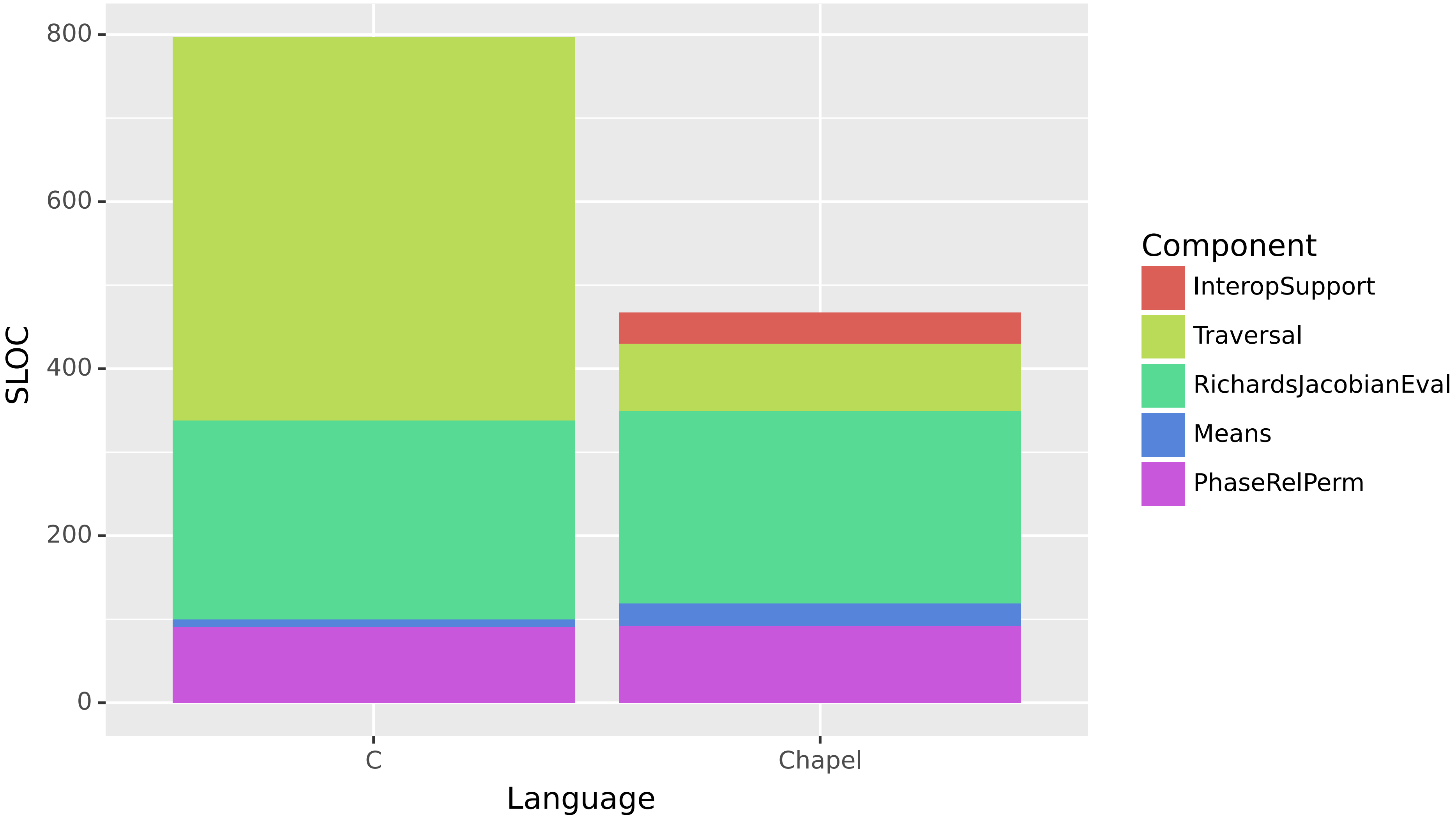
```c
#define GrGeomSurfLoopBoxes_default(i, j, k, fdir, grgeom, ix, iy, iz, nx, ny, nz, body) \
  {                                                                             \
    int PV_fdir[3];                                                             \
                                                                                \
    fdir = PV_fdir;                                                             \
    int PV_ixl, PV_iyl, PV_izl, PV_ixu, PV_iyu, PV_izu;                         \
    int *PV_visiting = NULL;                                                    \
    PF_UNUSED(PV_visiting);                                                     \
    for (int PV_f = 0; PV_f < GrGeomOctreeNumFaces; PV_f++)                     \
    {                                                                           \
      switch (PV_f)                                                             \
      {                                                                         \
        case GrGeomOctreeFaceL:                                                 \
          fdir[0] = -1; fdir[1] = 0; fdir[2] = 0;                               \
          break;                                                                \
        case GrGeomOctreeFaceR:                                                 \
          fdir[0] = 1; fdir[1] = 0; fdir[2] = 0;                                \
          break;                                                                \
        case GrGeomOctreeFaceD:                                                 \
          fdir[0] = 0; fdir[1] = -1; fdir[2] = 0;                               \
          break;                                                                \
        case GrGeomOctreeFaceU:                                                 \
          fdir[0] = 0; fdir[1] = 1; fdir[2] = 0;                                \
          break;                                                                \
        case GrGeomOctreeFaceB:                                                 \
          fdir[0] = 0; fdir[1] = 0; fdir[2] = -1;                               \
          break;                                                                \
        case GrGeomOctreeFaceF:                                                 \
          fdir[0] = 0; fdir[1] = 0; fdir[2] = 1;                                \
          break;                                                                \
        default:                                                                \
          fdir[0] = -9999; fdir[1] = -9999; fdir[2] = -99999;                   \
          break;                                                                \
      }                                                                         \
                                                                                \
      BoxArray* boxes = GrGeomSolidSurfaceBoxes(grgeom, PV_f);                  \
      for (int PV_box = 0; PV_box < BoxArraySize(boxes); PV_box++)              \
      {                                                                         \
        Box box = BoxArrayGetBox(boxes, PV_box);                                \
        /* find octree and region intersection */                               \
        PV_ixl = pfmax(ix, box.lo[0]);                                          \
        PV_iyl = pfmax(iy, box.lo[1]);                                          \
        PV_izl = pfmax(iz, box.lo[2]);                                          \
        PV_ixu = pfmin((ix + nx - 1), box.up[0]);                               \
        PV_iyu = pfmin((iy + ny - 1), box.up[1]);                               \
        PV_izu = pfmin((iz + nz - 1), box.up[2]);                               \
        for (k = PV_izl; k <= PV_izu; k++)                                      \
          for (j = PV_iyl; j <= PV_iyu; j++)                                    \
            for (i = PV_ixl; i <= PV_ixu; i++)                                  \
            {                                                                   \
              body;                                                             \
            }                                                                   \
      }                                                                         \
    }                                                                           \
  }
```

Surface Traversal, Chapel



```chapel
iter surfacePoints(ground, outerDomain) {
  for f in 0..<NumFaces do
    for box in ground.surfaceBoxes(f) do
      for (i,j,k) in box do
        yield (i,j,k,create_fdir(f));
}
```

CHAPEL NEEDS 40% LESS CODE



USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow		✓						
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

IMAGE PROCESSING FOR CORAL REEF DISSIMILARITY

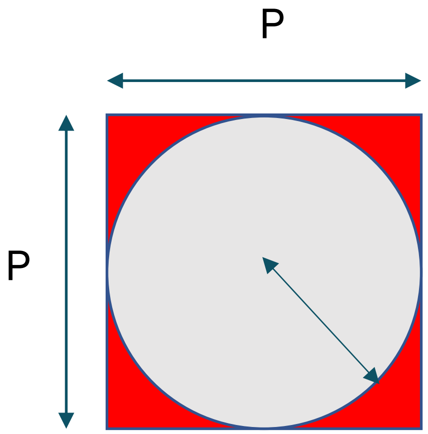
- **Analyzing images for coral reef diversity**

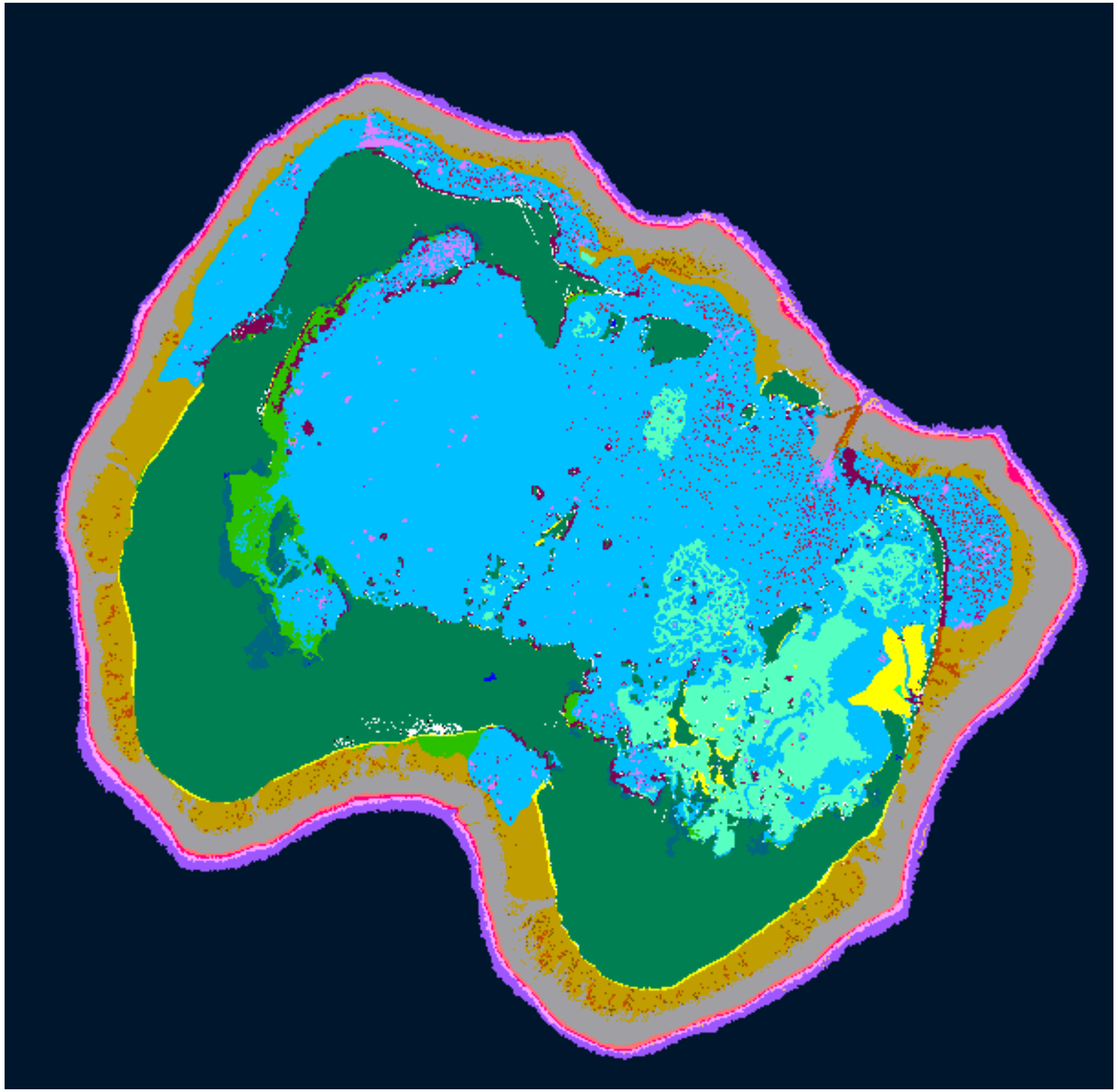
- **Less than 300 lines of code scales out to 100s of processors**

- **Full maps calculated in *seconds*, rather than days**

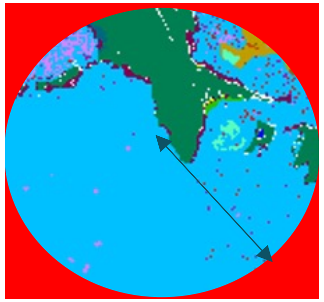
- **Task parallel patterns**
  - 'forall' in convolve_and_calculate doing shared memory, thread-level parallelism per node
  - 'coforall' in main doing distributed memory parallelism over swaths of the image
  - 'cobegin' could be used to input different file formats in parallel

Create a (P x P) mask to find all points within a given radius.

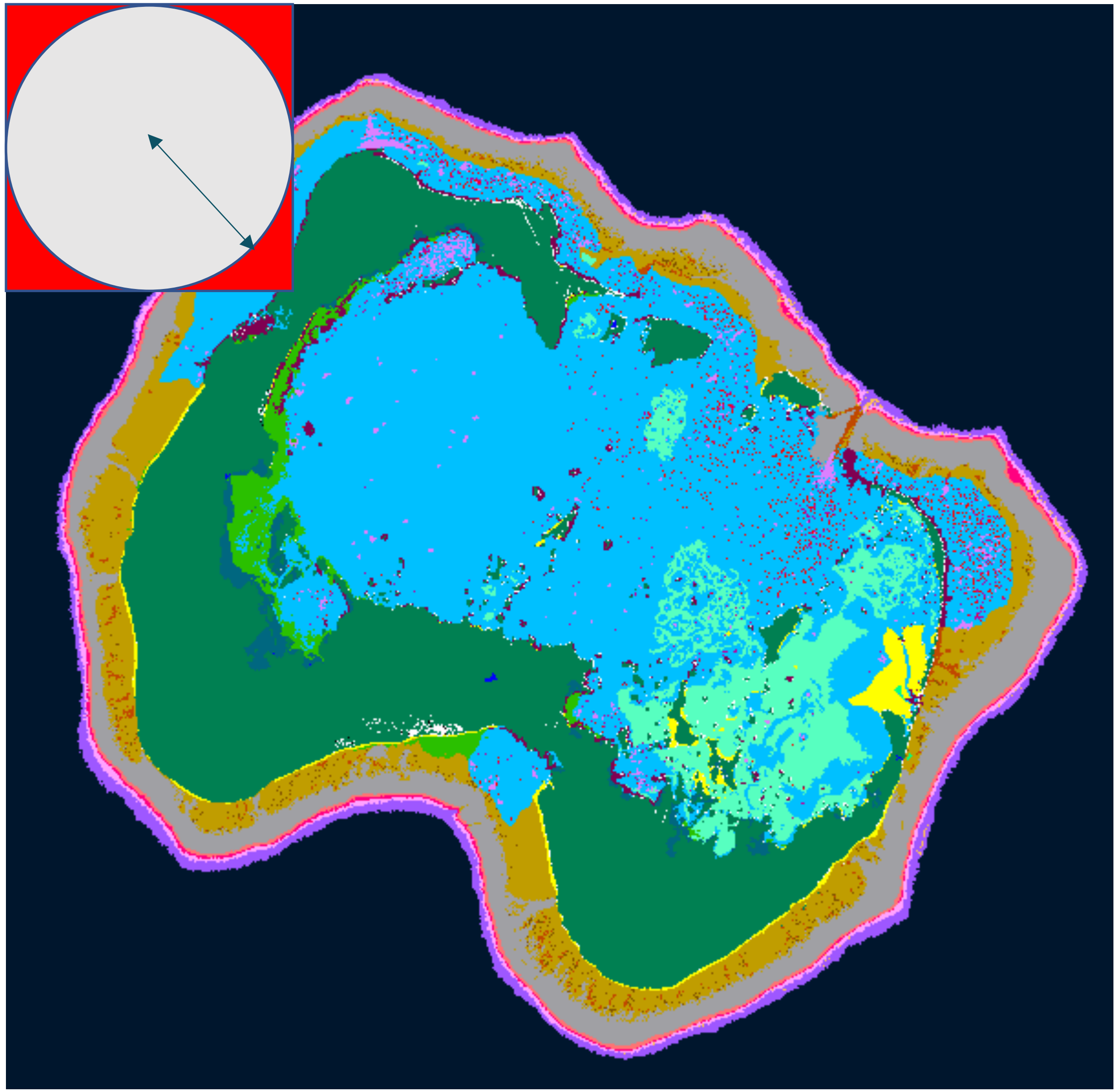




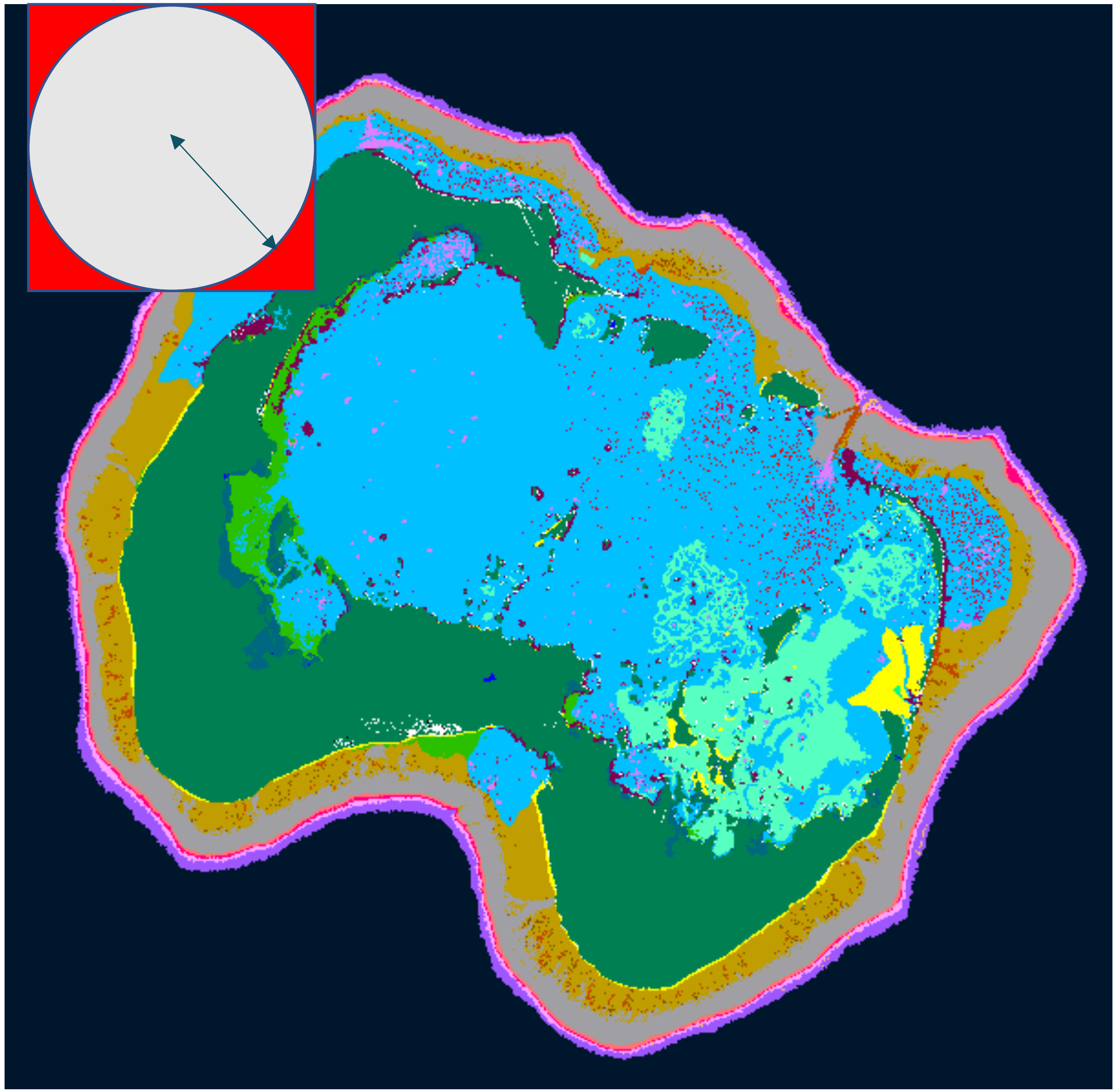
We convolve this mask over the entire domain and perform a weighted reduce at each location.



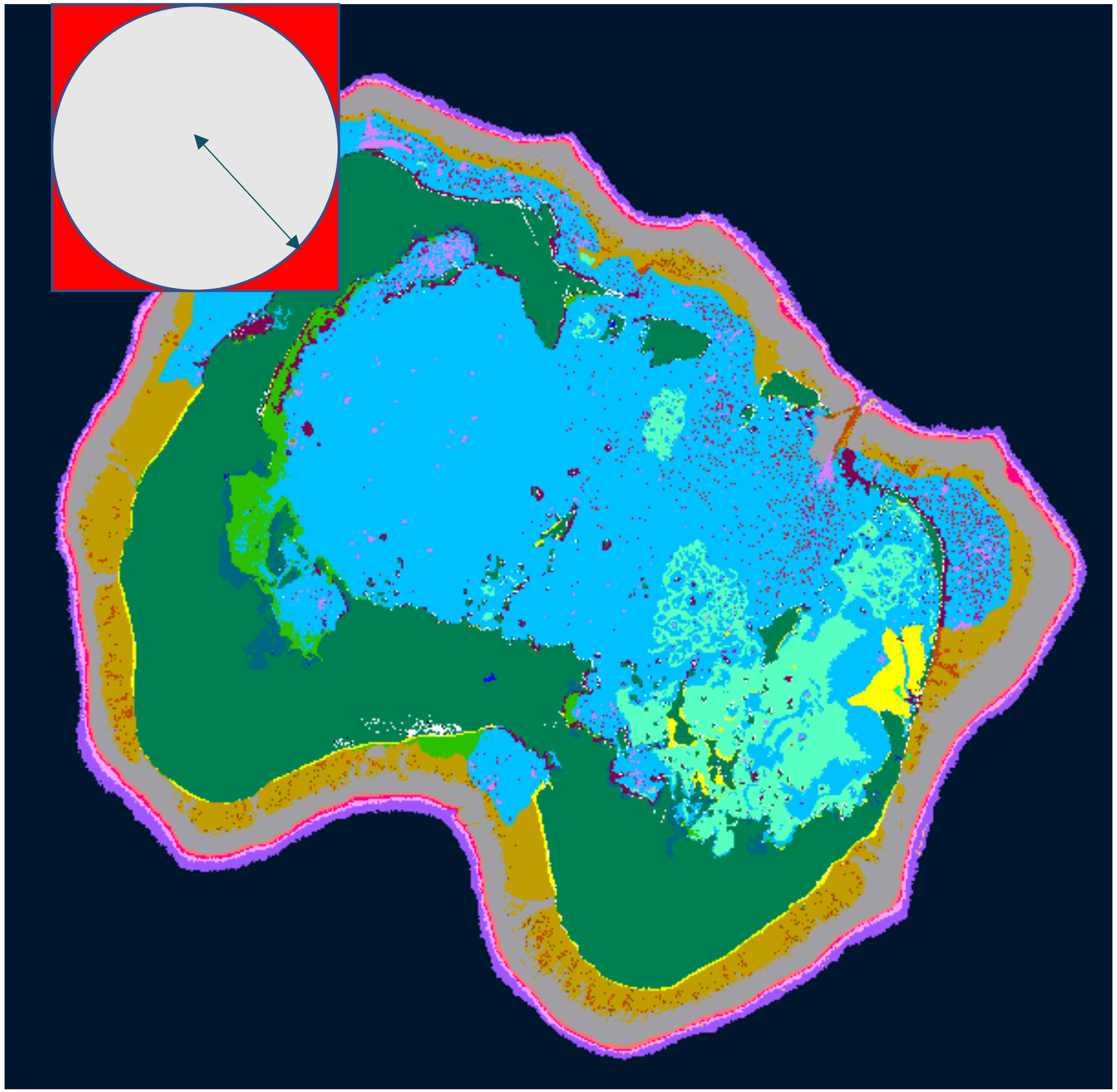
(Add up weighted values of all points in neighborhood)



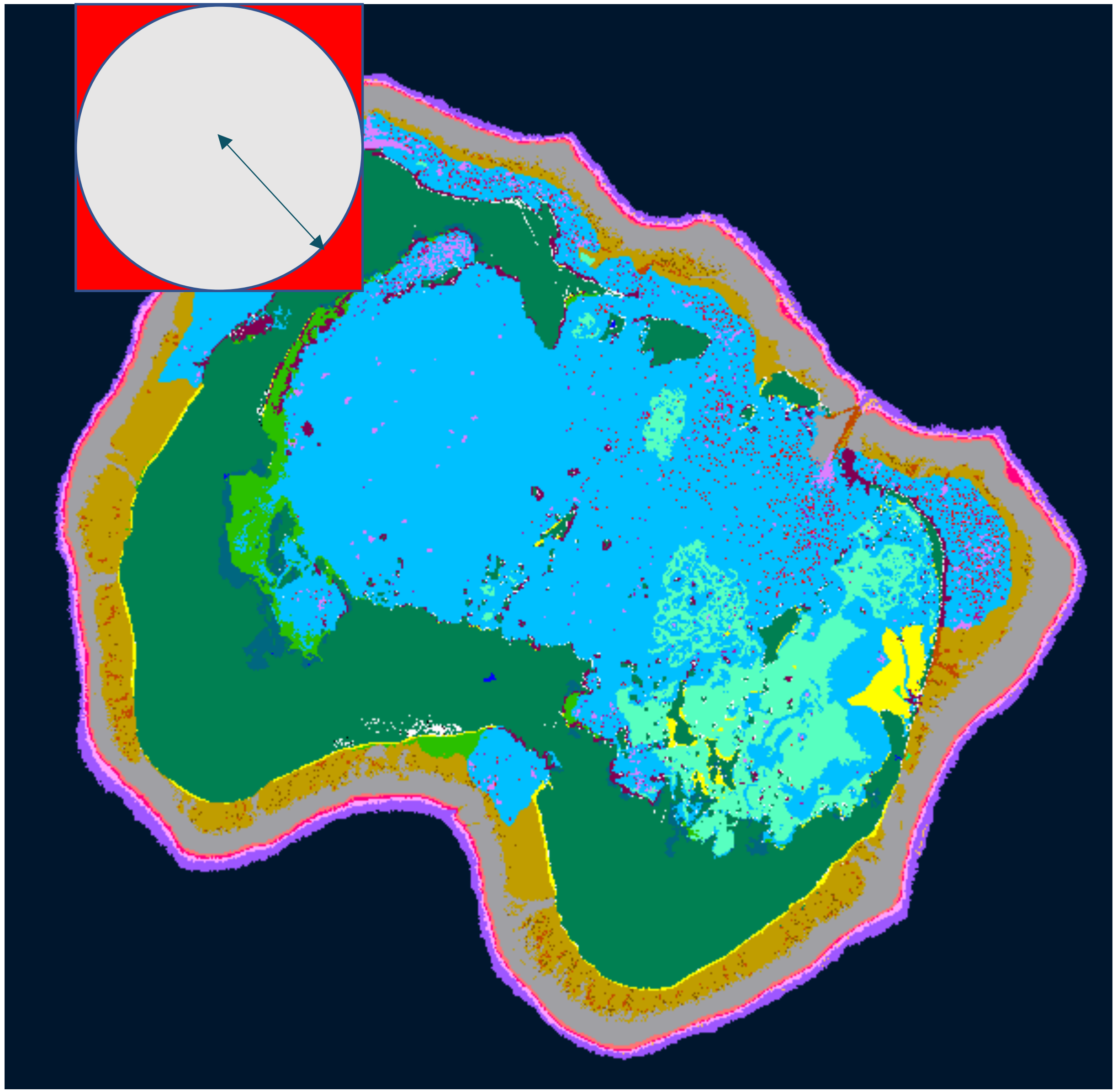
We convolve this mask over the entire domain and perform a weighted reduce at each location.



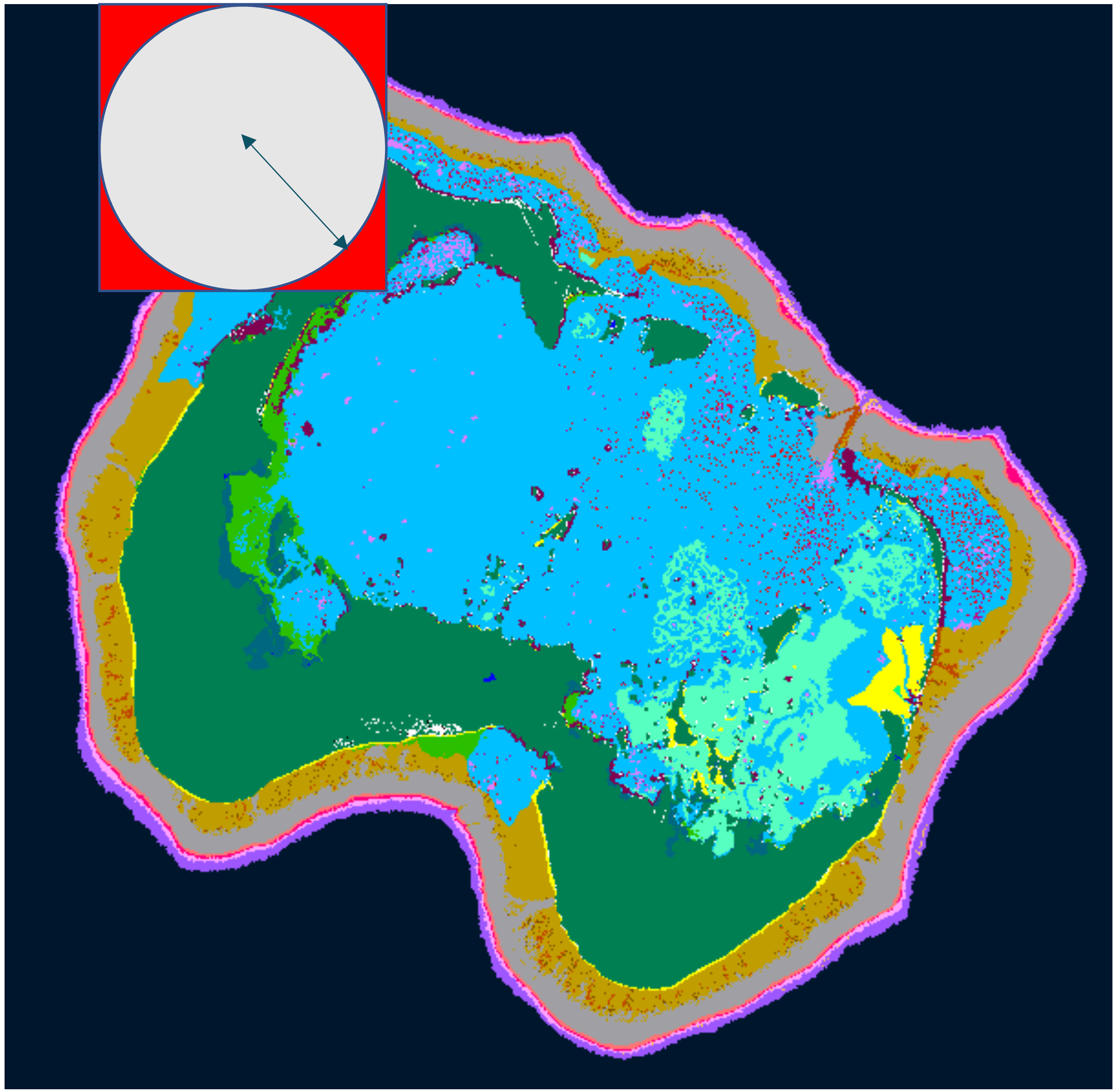
We convolve this mask over the entire domain and perform a weighted reduce at each location.



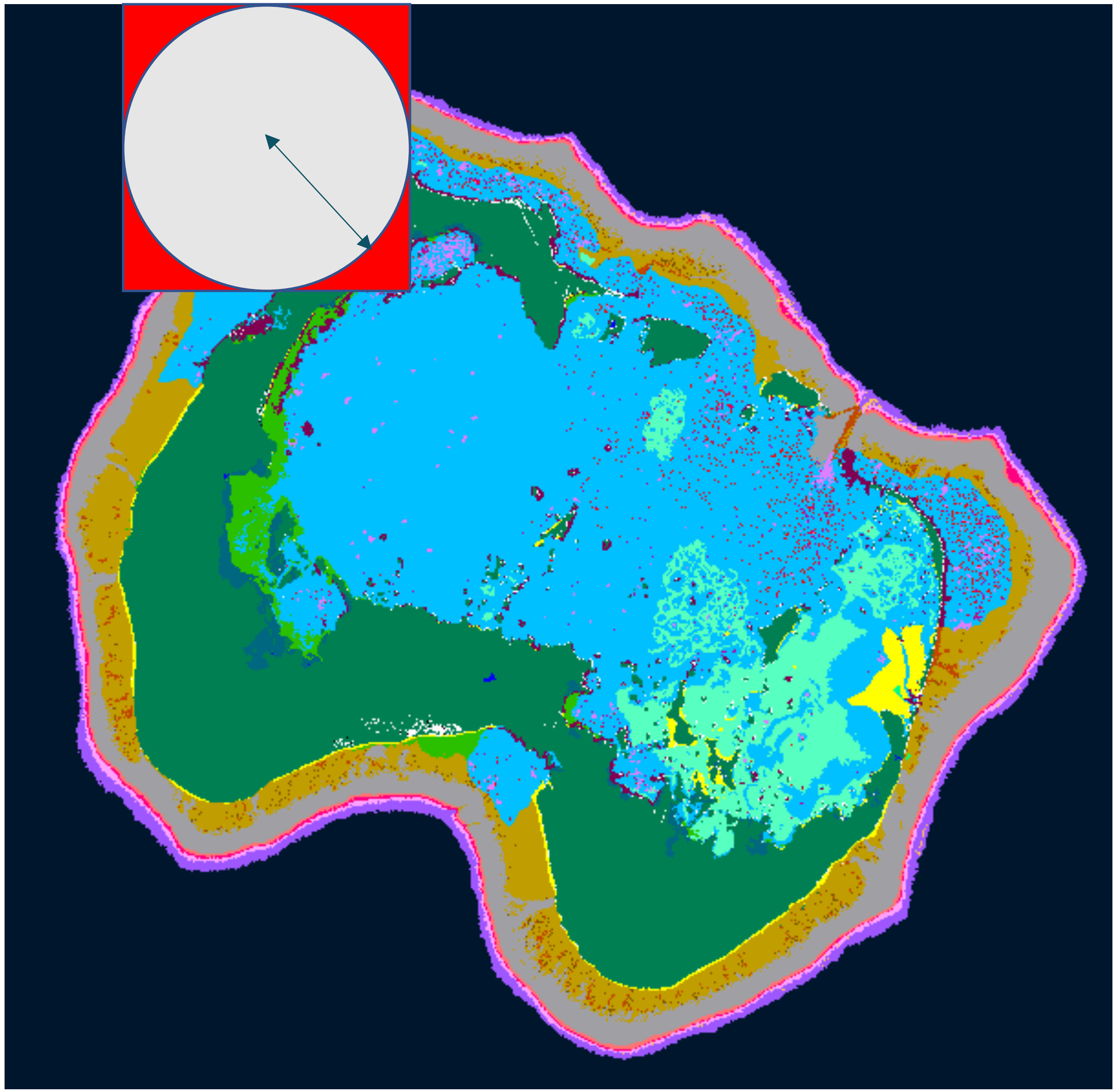
We convolve this mask over the entire domain and perform a weighted reduce at each location.



We convolve this mask over the entire domain and perform a weighted reduce at each location.

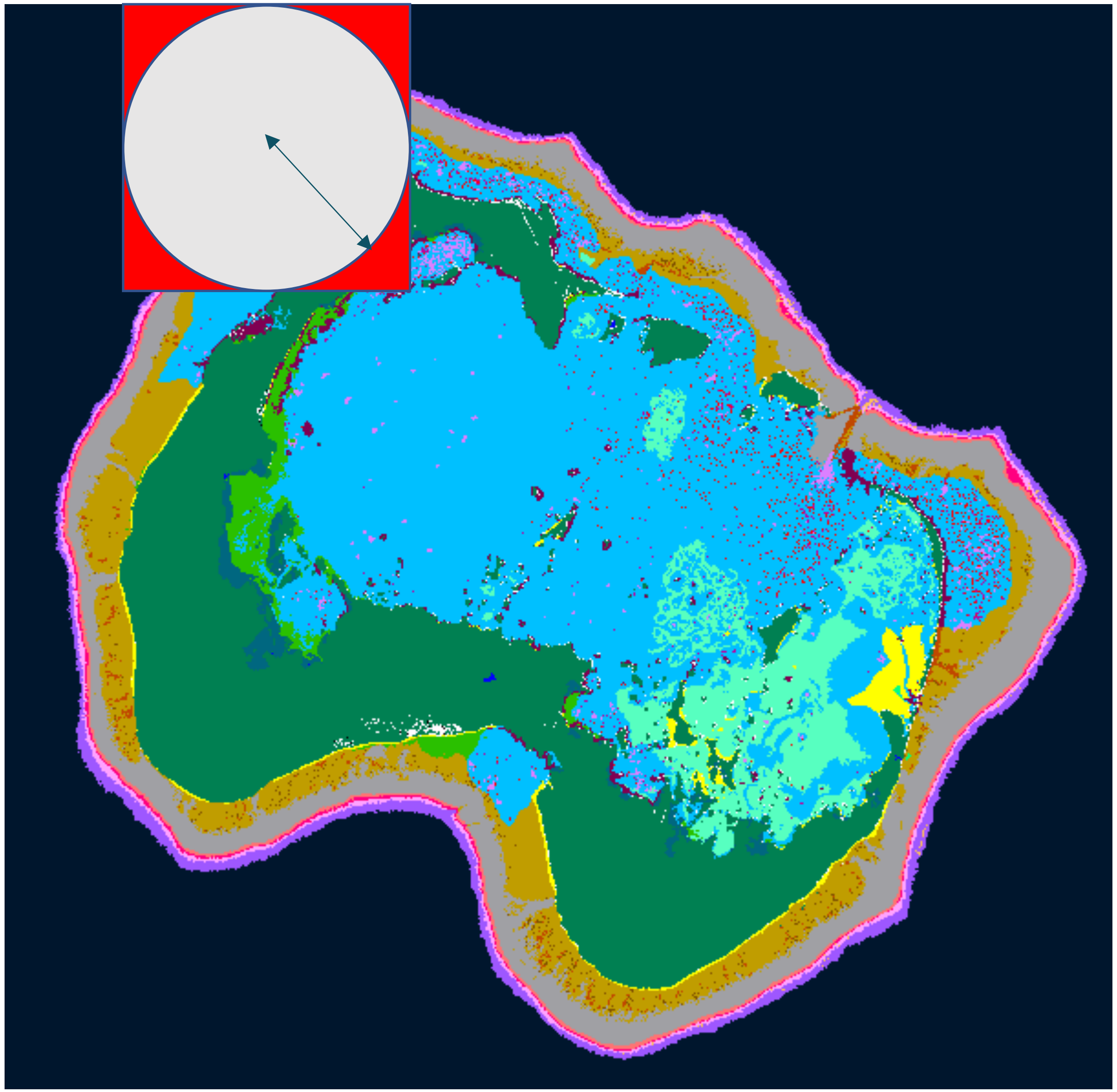


We convolve this mask over the entire domain and perform a weighted reduce at each location.

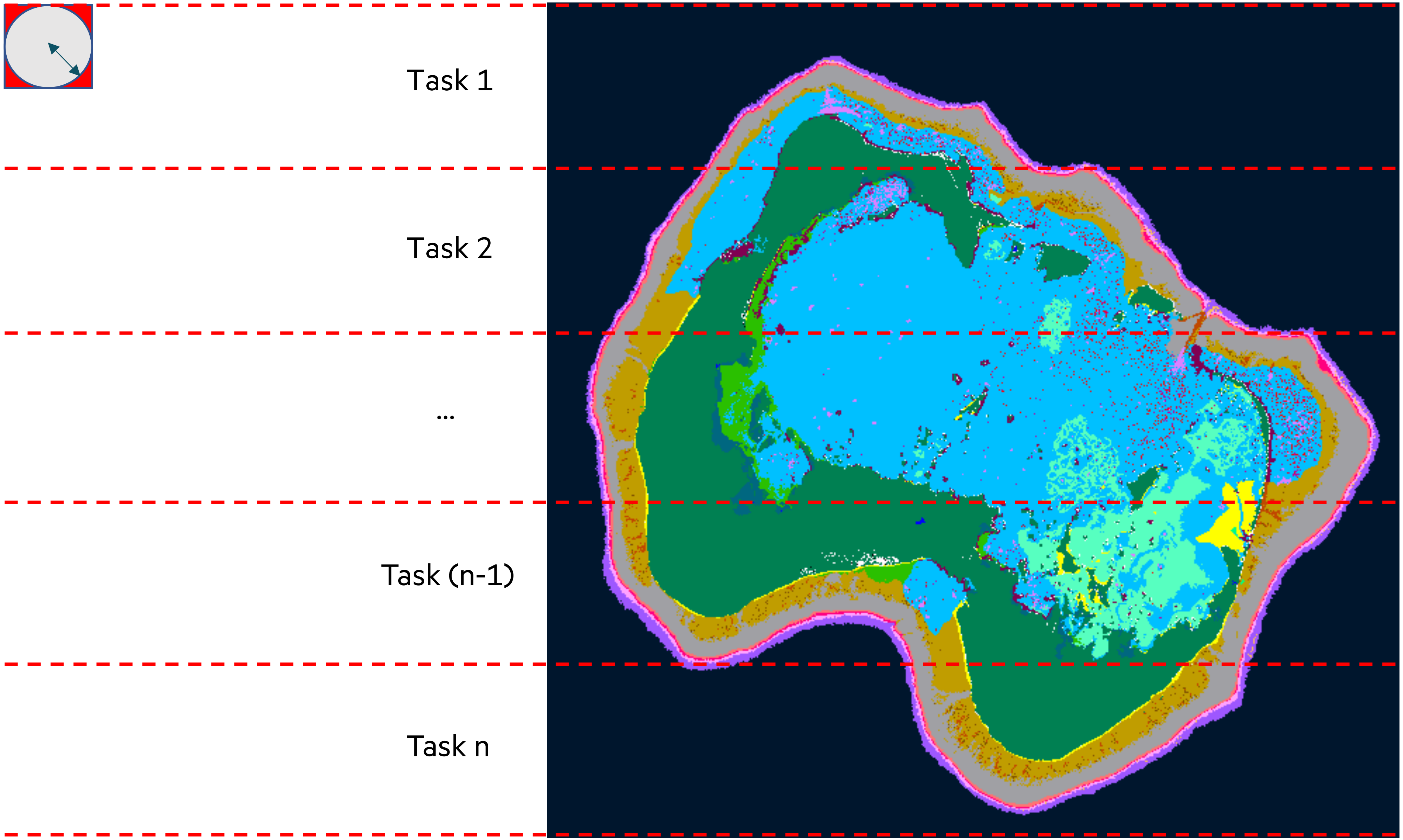


We convolve this mask over the entire domain and perform a weighted reduce at each location.

etc.



ALGORITHM: Divide the domain into “strips” and allocate a task for each strip.



Task 1

Task 2

...

Task (n-1)

Task n

USE OF TASKS IN SOME APPLICATIONS AND BENCHMARKS

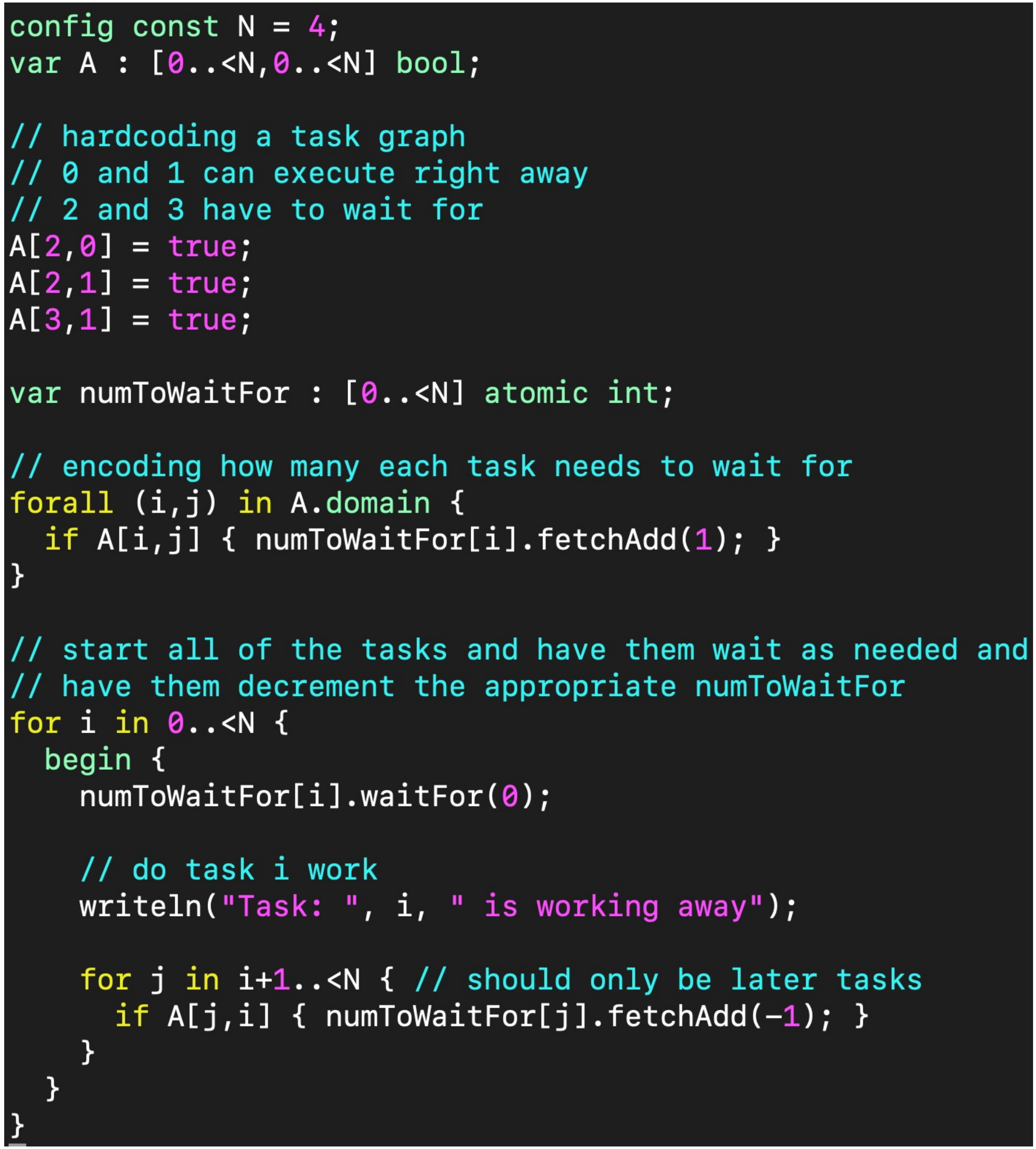
Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow		✓						
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

There will be fun questions throughout the talk

ARBITRARY TASK GRAPHS

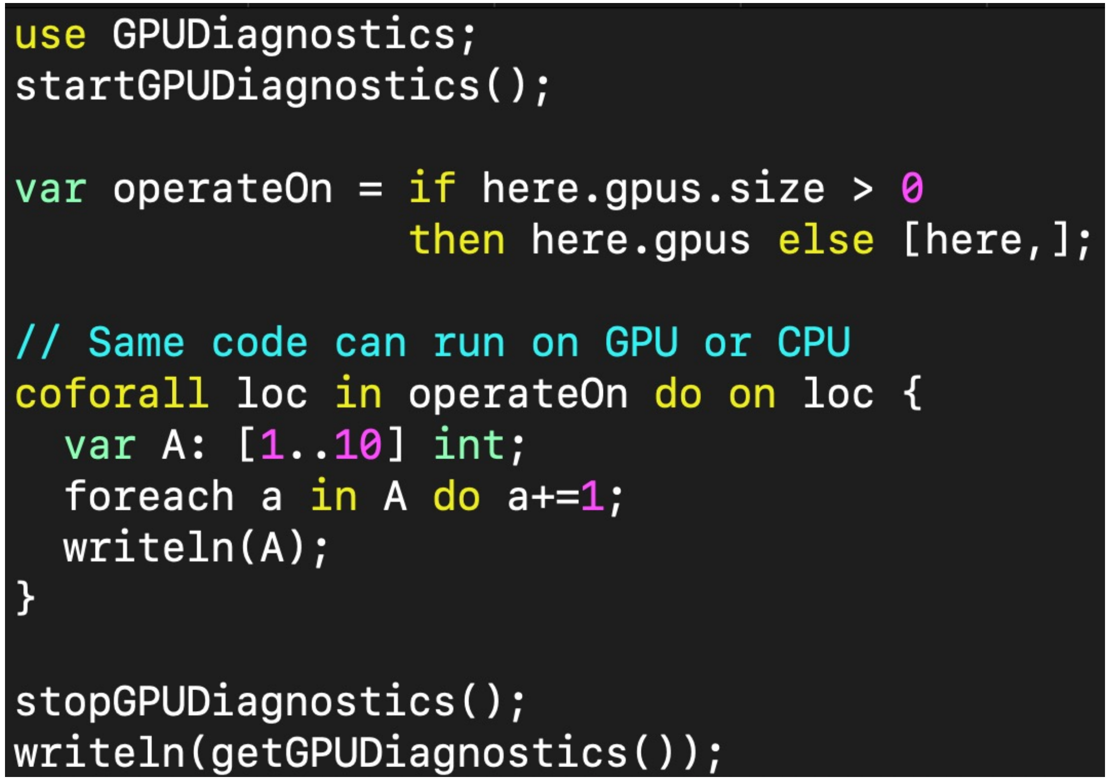
- **Encoding dependencies**
  - Array of 'atomic int'
  - 'numToWaitFor[i]' is the number of tasks that task i depends on
- **Starting asynchronous tasks**
  - 'for' loop
  - 'begin' block statement defines each task i
- **Waiting for dependencies to resolve**
  - Each task waits for the number of tasks it depends on to go to zero
  - 'numToWaitFor[i].waitFor(0)'
- **Tell dependent tasks when done**
  - 'numToWaitFor[j].fetchadd(-1)'



```
config const N = 4;
var A : [0..<N,0..<N] bool;

// hardcoding a task graph
// 0 and 1 can execute right away
// 2 and 3 have to wait for
A[2,0] = true;
A[2,1] = true;
A[3,1] = true;

var numToWaitFor : [0..<N] atomic int;

// encoding how many each task needs to wait for
forall (i,j) in A.domain {
  if A[i,j] { numToWaitFor[i].fetchAdd(1); }
}

// start all of the tasks and have them wait as needed and
// have them decrement the appropriate numToWaitFor
for i in 0..<N {
  begin {
    numToWaitFor[i].waitFor(0);

    // do task i work
    writeln("Task: ", i, " is working away");

    for j in i+1..<N { // should only be later tasks
      if A[j,i] { numToWaitFor[j].fetchAdd(-1); }
    }
  }
}
```

TASKS ON GPUS? GPU SUPPORT IN CHAPEL

- **Chapel compiler generating code for GPUs**
  - Nascent support for NVIDIA
  - Exploring AMD and Intel support
- **Chapel code calling CUDA examples**
  - https://github.com/chapel-lang/chapel/blob/main/test/gpu/interop/stream/streamChpl.chpl
  - https://github.com/chapel-lang/chapel/blob/main/test/gpu/interop/cuBLAS/cuBLAS.chpl
- **Key concepts**
  - Using the 'locale' concept to indicate execution and data allocation on GPUs
  - 'forall' and 'foreach' loops will be converted to kernels
  - Arrays declared in 'on here.gpus[0]' blocks are allocated on the GPU
- **For more info…**
  - https://chapel-lang.org/docs/technotes/gpu.html



```
use GPUDiagnostics;
startGPUDiagnostics();

var operateOn = if here.gpus.size > 0
                then here.gpus else [here,];

// Same code can run on GPU or CPU
coforall loc in operateOn do on loc {
  var A: [1..10] int;
  foreach a in A do a+=1;
  writeln(A);
}

stopGPUDiagnostics();
writeln(getGPUDiagnostics());
```

TALK TAKEAWAYS

- Chapel is a general-purpose programming language designed to leverage parallelism
- It is being used in some large production codes
  - **Performance**: The resulting applications are fast and scalable
  - **Programmability**: The code is relatively easy to write and maintain
- Chapel supports many different **task parallelism patterns**

Application	Distributed 'coforall'	Threaded 'coforall'	Asynchronous 'begin'	'cobegin'	sync or atomic vars	subprocesses	forall	scan
Hello World	✓	✓						
HPO	✓	✓				✓		
Arkouda	✓	✓					✓	✓
CHAMPS	✓	✓						
ChOp	✓		✓		✓		✓	
ParFlow							✓	
Coral Reef	✓	✓		✓			✓	
Task Graph			✓		✓			

Poll Everywhere link: pollev.com/michellestrout402

Let me know your thoughts in a short survey

USE A CONTAINER TO CHECKOUT SOME CHAPEL EXAMPLES

- **Links for some Chapel examples**
  - Blog posts for Advent of Code, https://chapel-lang.org/blog/index.html
    - Especially check out days 11 and 12 since they cover sync variables and atomics
  - Wavelet example by Jeremiah Corrado, Slides and Code at https://github.com/mstrout/ChapelForPythonProgrammersFeb2023/tree/main/wavelet_example
  - Primers, https://chapel-lang.org/docs/primers/index.html
  - Test directory in main repository, https://github.com/chapel-lang/chapel/tree/main/test

- **Using a container on your laptop**
  - See https://github.com/mstrout/ChapelForPythonProgrammersFeb2023 for some example code
  - First, install podman or docker for your machine and then start them up
  - Then, the below commands work with podman or docker

```
podman pull docker.io/chapel/chapel     # takes about 3 minutes
cd ChapelForPythonProgrammersFeb2023    # assuming git clone has happened
podman run --rm -v "$PWD":/myapp -w /myapp chapel/chapel chpl hello.chpl
podman run --rm -v "$PWD":/myapp -w /myapp chapel/chapel ./hello
```

CHAPEL RESOURCES

Chapel homepage: https://chapel-lang.org

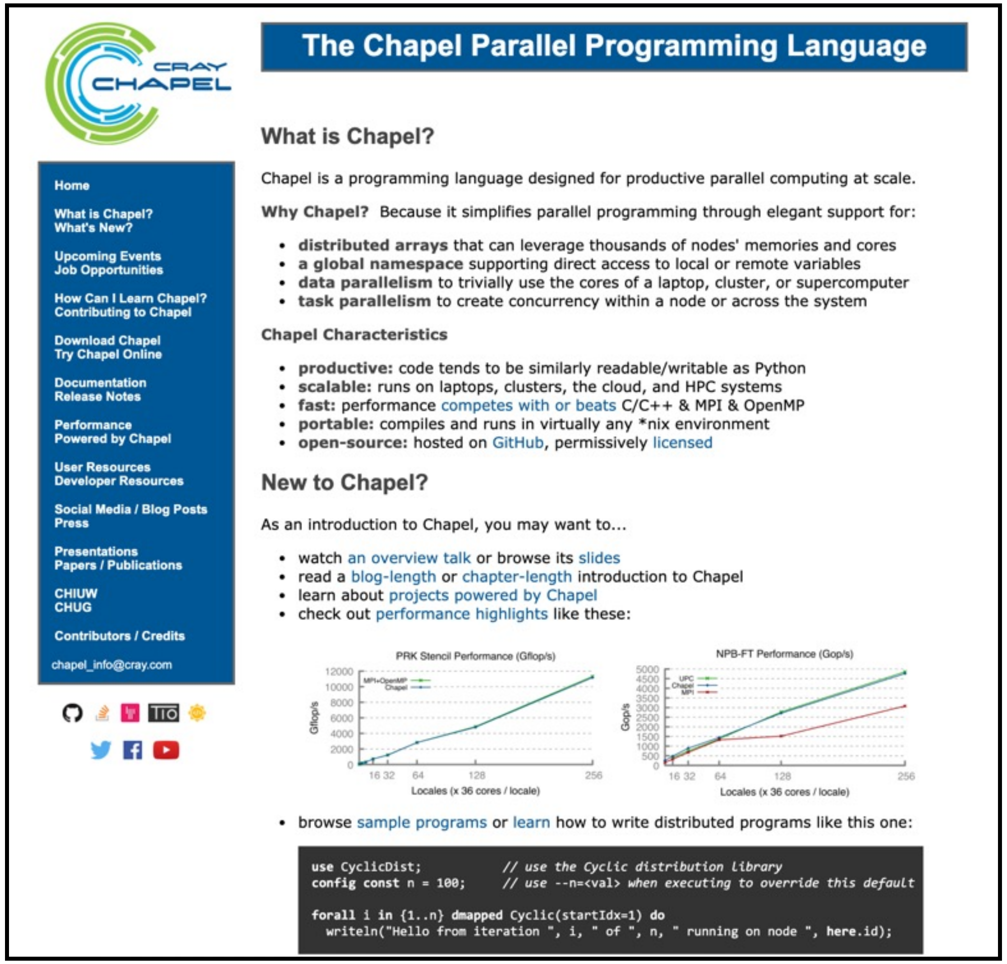
- (points to all other resources)

Social Media:

- Twitter: @ChapelLanguage
- Facebook: @ChapelLanguage
- YouTube: http://www.youtube.com/c/ChapelParallelProgrammingLanguage

Community Discussion / Support:

- Discourse: https://chapel.discourse.group/
- Gitter: https://gitter.im/chapel-lang/chapel
- Stack Overflow: https://stackoverflow.com/questions/tagged/chapel
- GitHub Issues: https://github.com/chapel-lang/chapel/issues



CRAY CHAPEL

The Chapel Parallel Programming Language

Home

What is Chapel?
What's New?

Upcoming Events
Job Opportunities

How Can I Learn Chapel?
Contributing to Chapel

Download Chapel
Try Chapel Online

Documentation
Release Notes

Performance
Powered by Chapel

User Resources
Developer Resources

Social Media / Blog Posts
Press

Presentations
Papers / Publications

CHIUW
CHUG

Contributors / Credits

chapel_info@cray.com

What is Chapel?

Chapel is a programming language designed for productive parallel computing at scale.

Why Chapel? Because it simplifies parallel programming through elegant support for:

- **distributed arrays** that can leverage thousands of nodes' memories and cores
- **a global namespace** supporting direct access to local or remote variables
- **data parallelism** to trivially use the cores of a laptop, cluster, or supercomputer
- **task parallelism** to create concurrency within a node or across the system

Chapel Characteristics

- **productive:** code tends to be similarly readable/writable as Python
- **scalable:** runs on laptops, clusters, the cloud, and HPC systems
- **fast:** performance competes with or beats C/C++ & MPI & OpenMP
- **portable:** compiles and runs in virtually any *nix environment
- **open-source:** hosted on GitHub, permissively licensed

New to Chapel?

As an introduction to Chapel, you may want to...

- watch an overview talk or browse its slides
- read a blog-length or chapter-length introduction to Chapel
- learn about projects powered by Chapel
- check out performance highlights like these:

- browse sample programs or learn how to write distributed programs like this one:

```
use CyclicDist;           // use the Cyclic distribution library
config const n = 100;     // use --n=<val> when executing to override this default

forall i in {1..n} dmapped Cyclic(startIdx=1) do
  writeln("Hello from iteration ", i, " of ", n, " running on node ", here.id);
```

CHAPEL TASKS ARE EFFICIENT

"Task Bench: A Parameterized Benchmark for Evaluating Parallel Runtime Performance" by ***Elliott Slaughter****, Wei Wu, Yuankun Fu, Legend Brandenburg, Nicolai Garcia, Wilhem Kautz, Emily Marx, Kaleb S. Morris, Qinglei Cao, George Bosilca, Seema Mirchandaney, Wonchan Lee, Sean Treichler, Patrick McCormick, and Alex Aiken. In the International Conference for High Performance Computing, Networking, Storage and Analysis (SC 2020).*

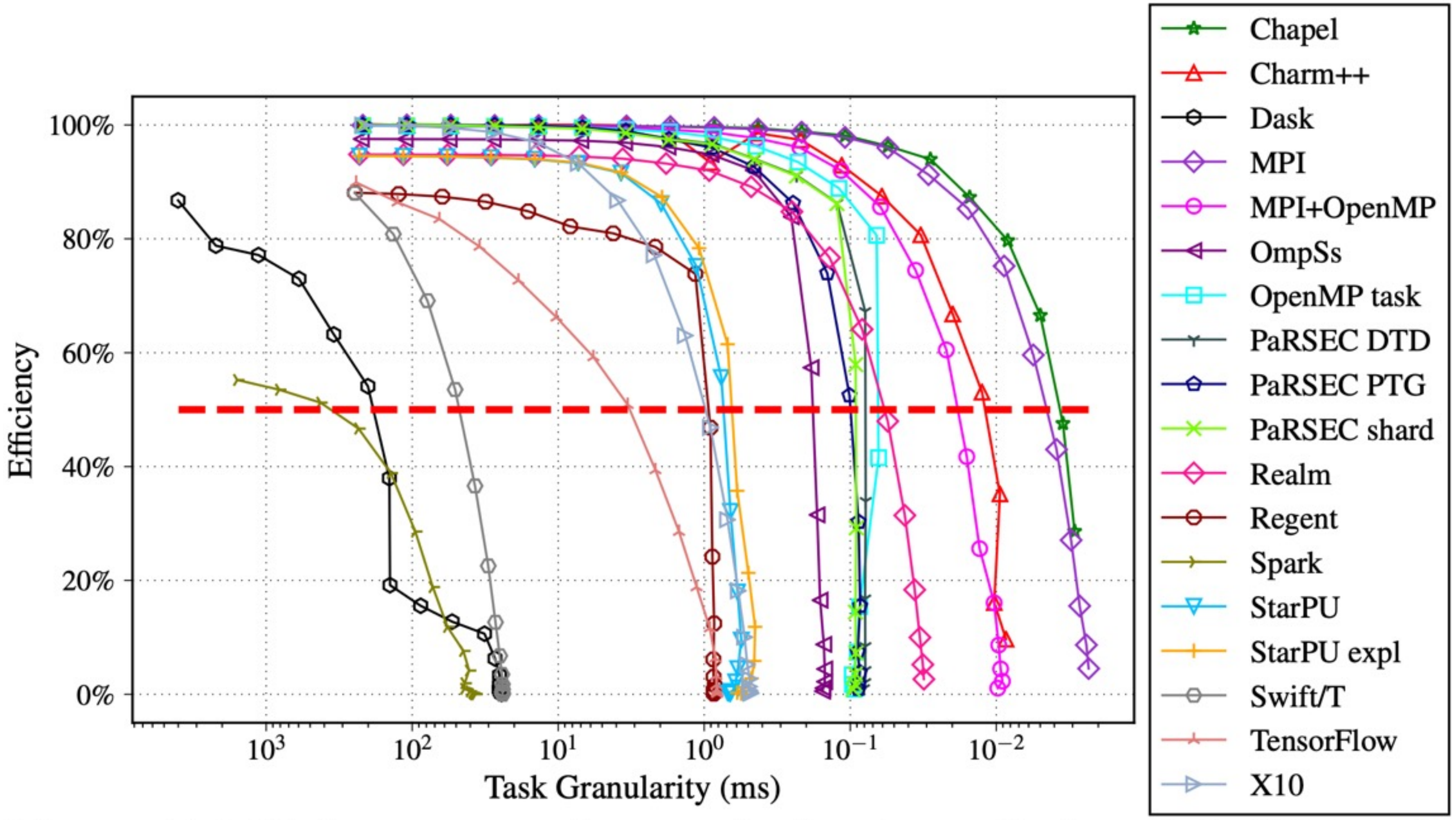


Figure 7: Efficiency vs task granularity (stencil, 1 node). Higher is better.

CHAPEL DOES WELL EVEN WHEN # OF DEPENDENCIES INCREASE

"Task Bench: A Parameterized Benchmark for Evaluating Parallel Runtime Performance" by ***Elliott Slaughter****, Wei Wu, Yuankun Fu, Legend Brandenburg, Nicolai Garcia, Wilhem Kautz, Emily Marx, Kaleb S. Morris, Qinglei Cao, George Bosilca, Seema Mirchandaney, Wonchan Lee, Sean Treichler, Patrick McCormick, and Alex Aiken. In the International Conference for High Performance Computing, Networking, Storage and Analysis (SC 2020).*

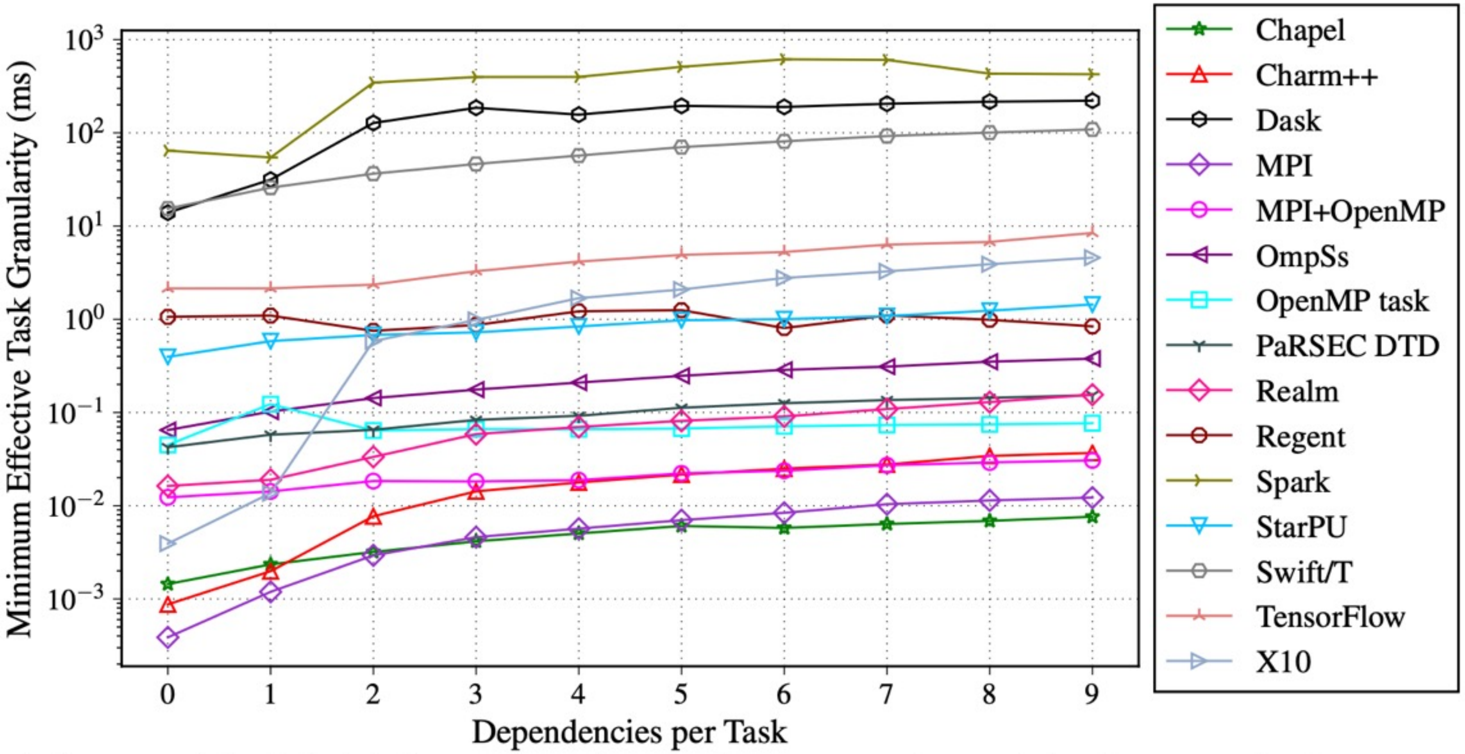


Figure 10: METG vs deps/task (nearest, 1 node). Lower is better.