CHAPEL AND OPEN PRODUCTIVE PARALLEL COMPUTING AT SCALE

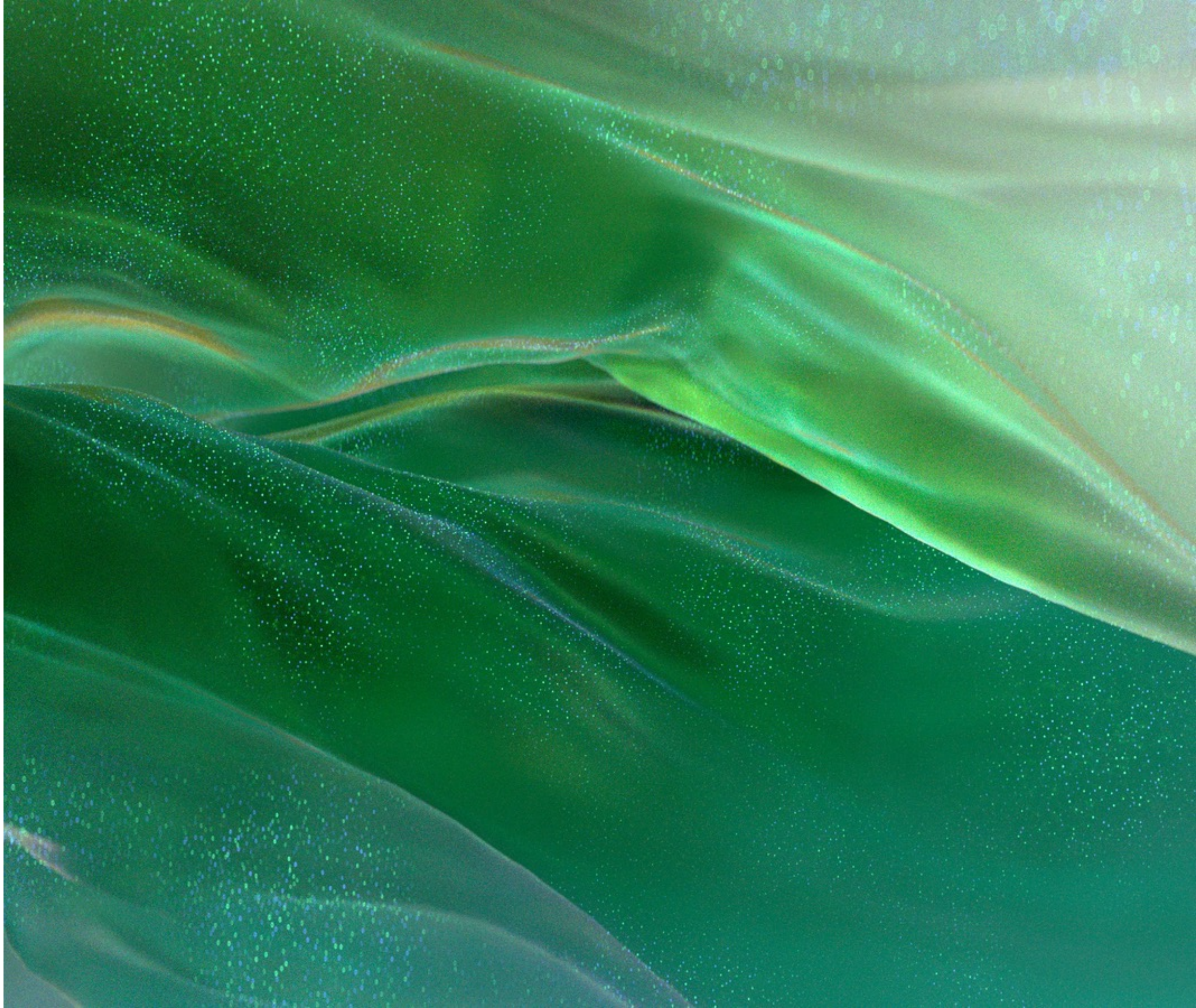
Michael Ferguson

February 7, 2024

Hewlett Packard Enterprise

OUTLINE

- Motivation: Sorting
- What is Chapel?
- Comparing to Other Languages
- What do Chapel users say?
- Applications written in Chapel
- Demos and Q&A
- Wrap-Up



SORTING IN STANDARD LIBRARIES

Parallelism is Essential to Performance

SORTING IN STANDARD LIBRARIES

- Most standard libraries include a ‘sort’ routine

- It’s an essential building block
  - supports GroupBy in data analysis tools such as Arkouda or Pandas
  - supports indexing, searching, many other algorithms

- Let’s investigate the performance of standard library ‘sort’ routines

- Why focus on standard libraries? They
  - are more likely to be used in practice than other implementations
  - show what a programming language has to offer
  - set an example for libraries
  - form a common language for programmers

THE BENCHMARK

- Sort 1GiB of 64-bit integers
  - i.e. 128*1024*1024 integers

- Use random values

THE TEST SYSTEM

My PC!

CPU: AMD Ryzen 9 7950X
- 4.5GHz, 16 cores, 32 threads

Memory: 64 GiB of DDR5 memory
- 5200MT/s CL40

Motherboard:
- Gigabyte X670 Aorus Elite AX

OS: Ubuntu 23.10

Pawallel Programming Consultant & Benchmark PC

Total Cost:
~ $1500

IN PYTHON

```
import random
import time

# generate an array of random integers
n = 128*1024*1024
array = [random.randint(0, 0xffffffffffffffff) for _ in range(n)]

start = time.time()
# use the standard library to sort the array
array.sort()
stop = time.time()

# print out the performance achieved
elapsed = stop-start
print ("Sorted", n, "elements in", elapsed, "seconds")
print (n/elapsed/1_000_000, "million elements sorted per second")
```

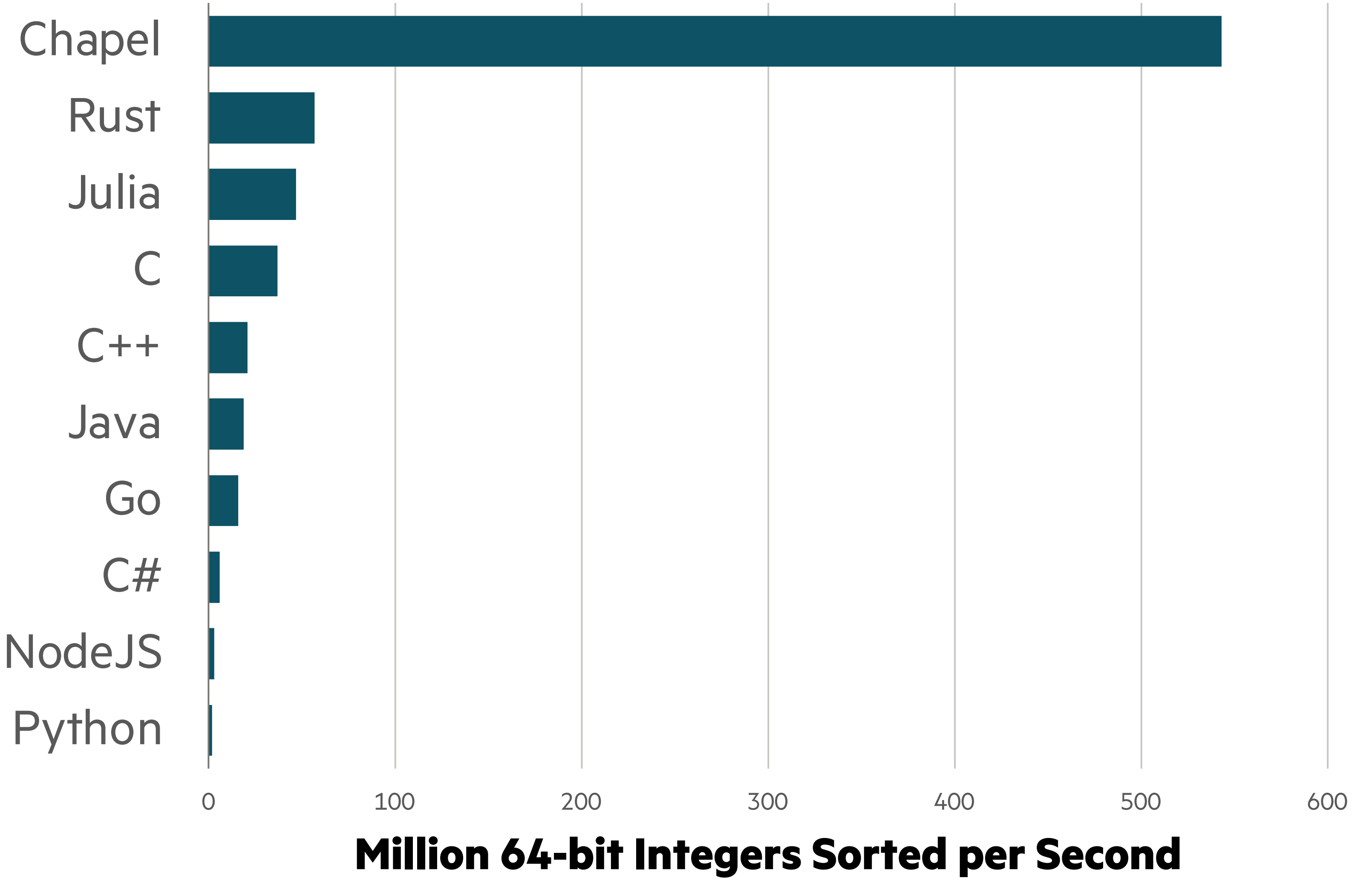
IN CHAPEL

```
use Time, Sort, Random;

// generate an array of random integers
config const n = 128*1024*1024;
var A: [0..<n] uint;              // note: int, uint default to 64 bits
fillRandom(A);                    // set the elements to random values

var timer: stopwatch;
timer.start();
// use the standard library to sort the array
sort(A);

// print out the performance achieved
var elapsed = timer.elapsed();
writeln("Sorted ", n, " elements in ", elapsed, " seconds");
writeln(n/elapsed/1_000_000, " million elements sorted per second");
```

BOTH PROGRAMS ARE SIMPLE

How do they perform?

RESULTS ON THE PC



10 times faster

than the other languages measured in this experiment

15 times faster

than C with ‘qsort’

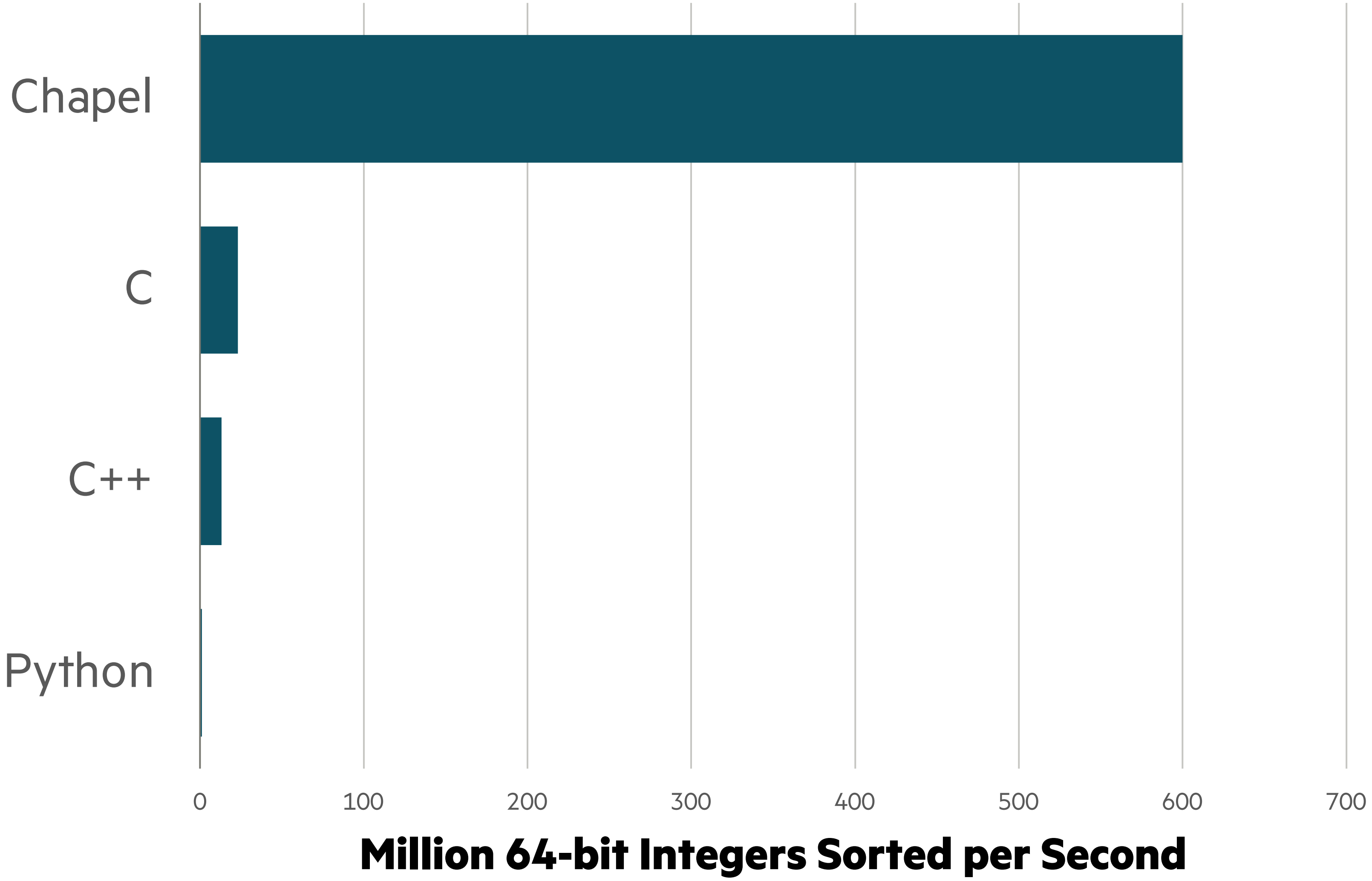
200 times faster

than Python’s ‘sort’

BUT I HAVE A SERVER

How does that impact things?

RESULTS ON 1 SOCKET AMD EPYC 7543: 32 CORES



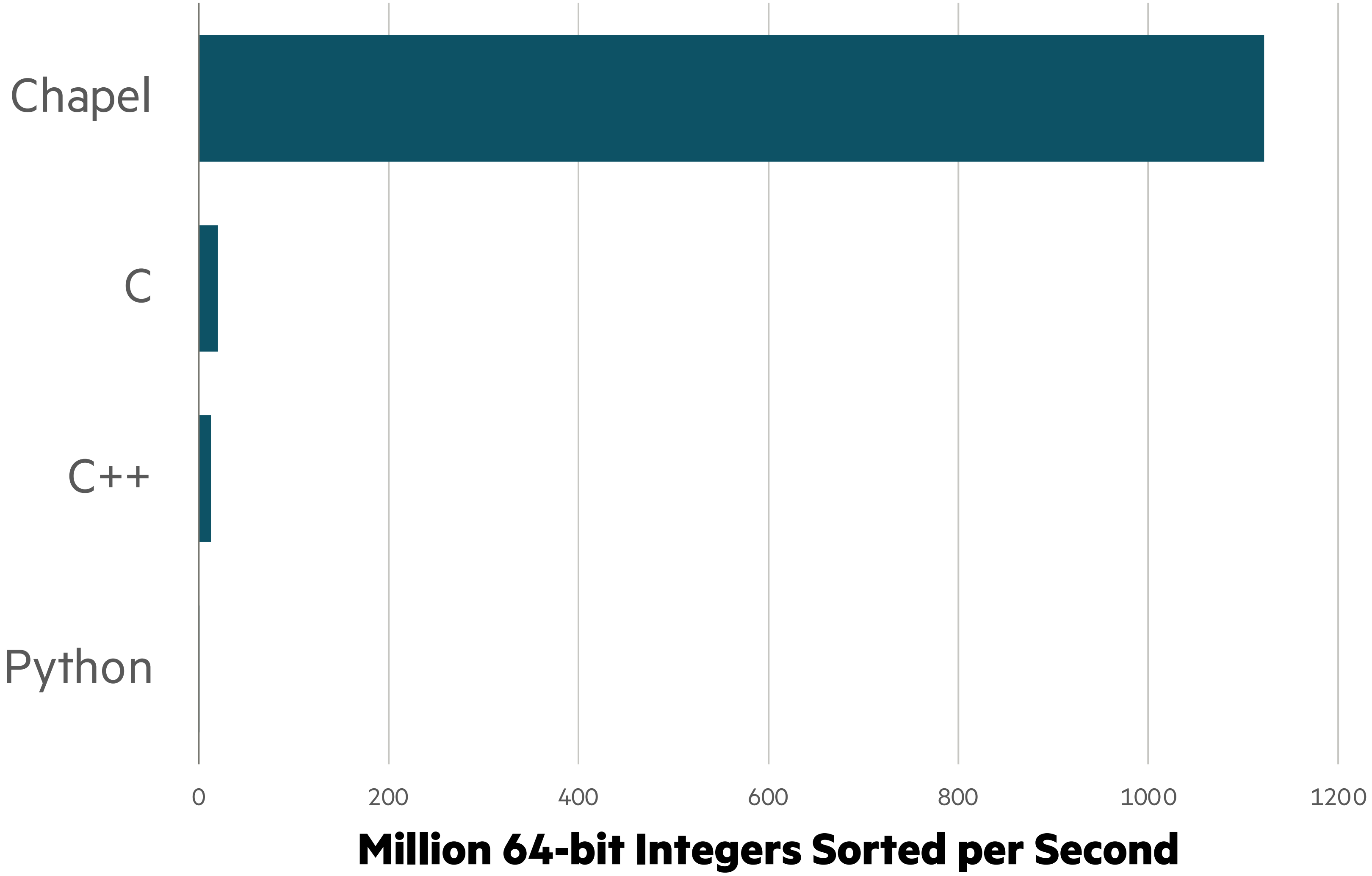
25 times faster

than C with ‘qsort’

400 times faster

than Python

RESULTS ON 2 SOCKET AMD EPYC 7763: 64 CORES



50 times faster

than C with ‘qsort’

1000 times faster

than Python

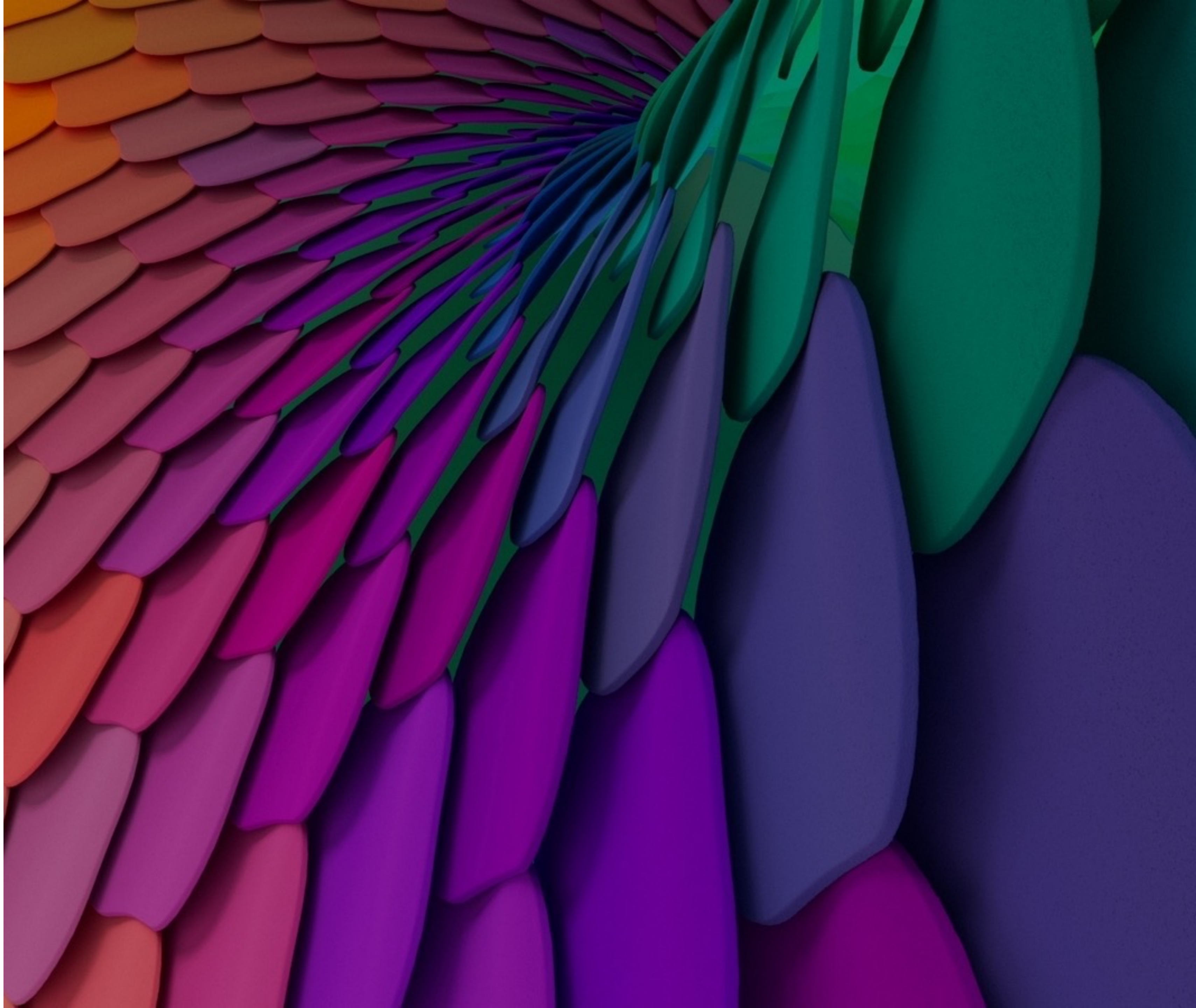
WHY?

The main reason:

- Chapel used all the cores
- others used 1 core

EASY PARALLELISM

- A parallel programming language can make it easy to use parallel hardware
- A parallel standard library brings additional productivity
- Chapel is a language built for parallelism & includes a parallel standard library



WHAT IS CHAPEL?

Productive Parallel Programming

WHAT IS CHAPEL?

Chapel: A modern parallel programming language

- portable & scalable
- open-source & collaborative

Goals:

- Support general parallel programming
- Make parallel programming at scale far more productive

PRODUCTIVE PARALLEL PROGRAMMING

A Potential Definition

Imagine a programming language for parallel computing that was as…

…**programmable** as Python

…yet also as…

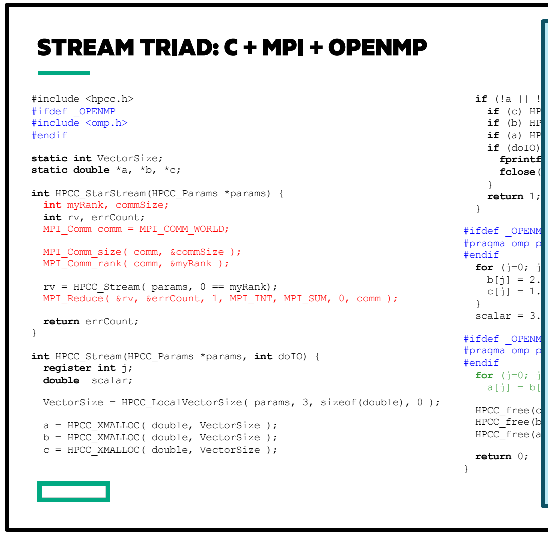
…**fast** as Fortran/C/C++

…**scalable** as MPI/SHMEM

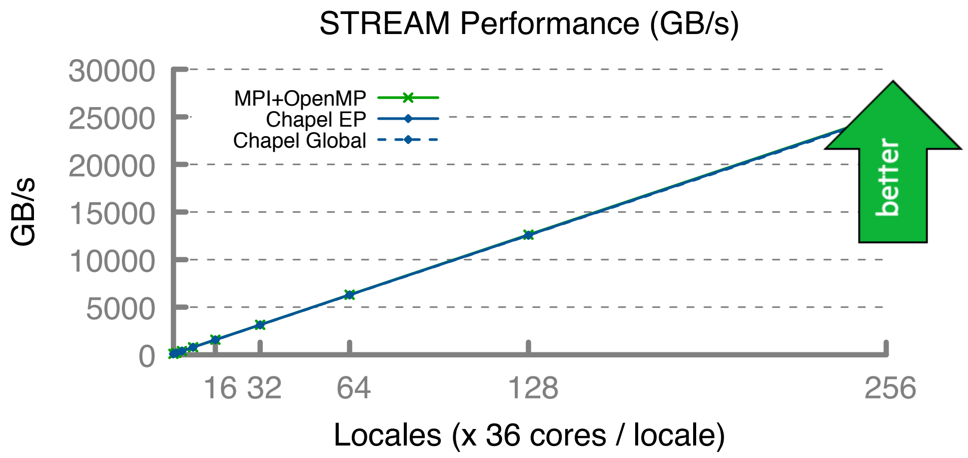
…**GPU-ready** as CUDA/OpenMP/OpenCL/OpenACC/…

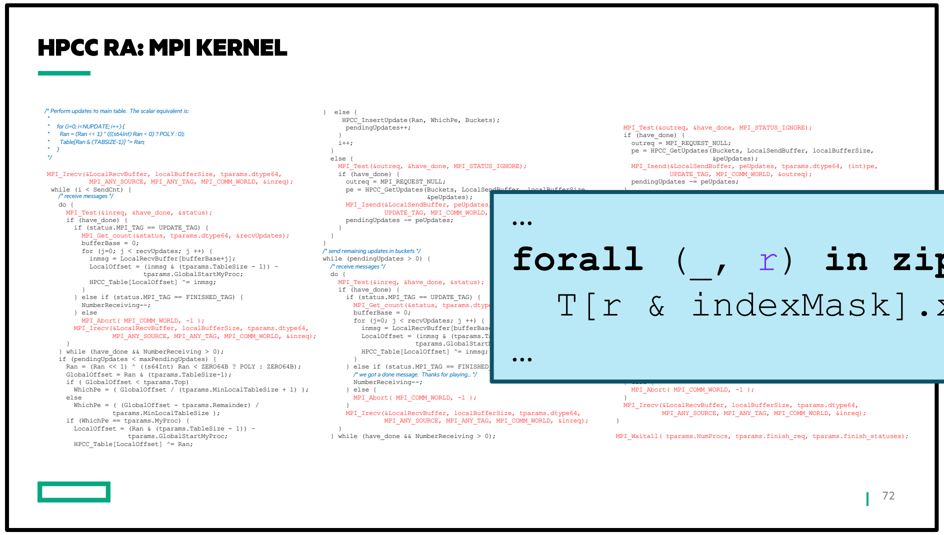
…**portable** as C

CHAPEL IS COMPACT, CLEAR, AND COMPETITIVE

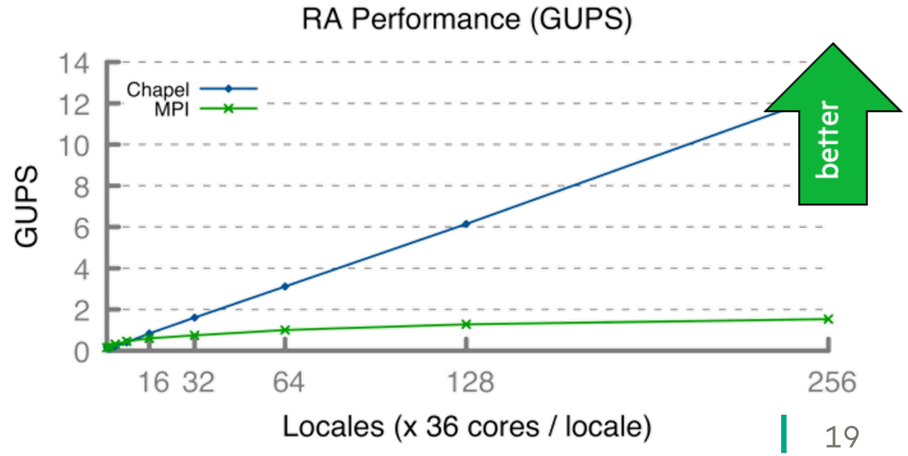



```
use BlockDist;

config const n = 1_000_000,
             alpha = 0.01;
const Dom = Block.createDomain({1..n});
var A, B, C: [Dom] real;

B = 2.0;
C = 1.0;

A = B + alpha * C;
```






```
...
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
...
```

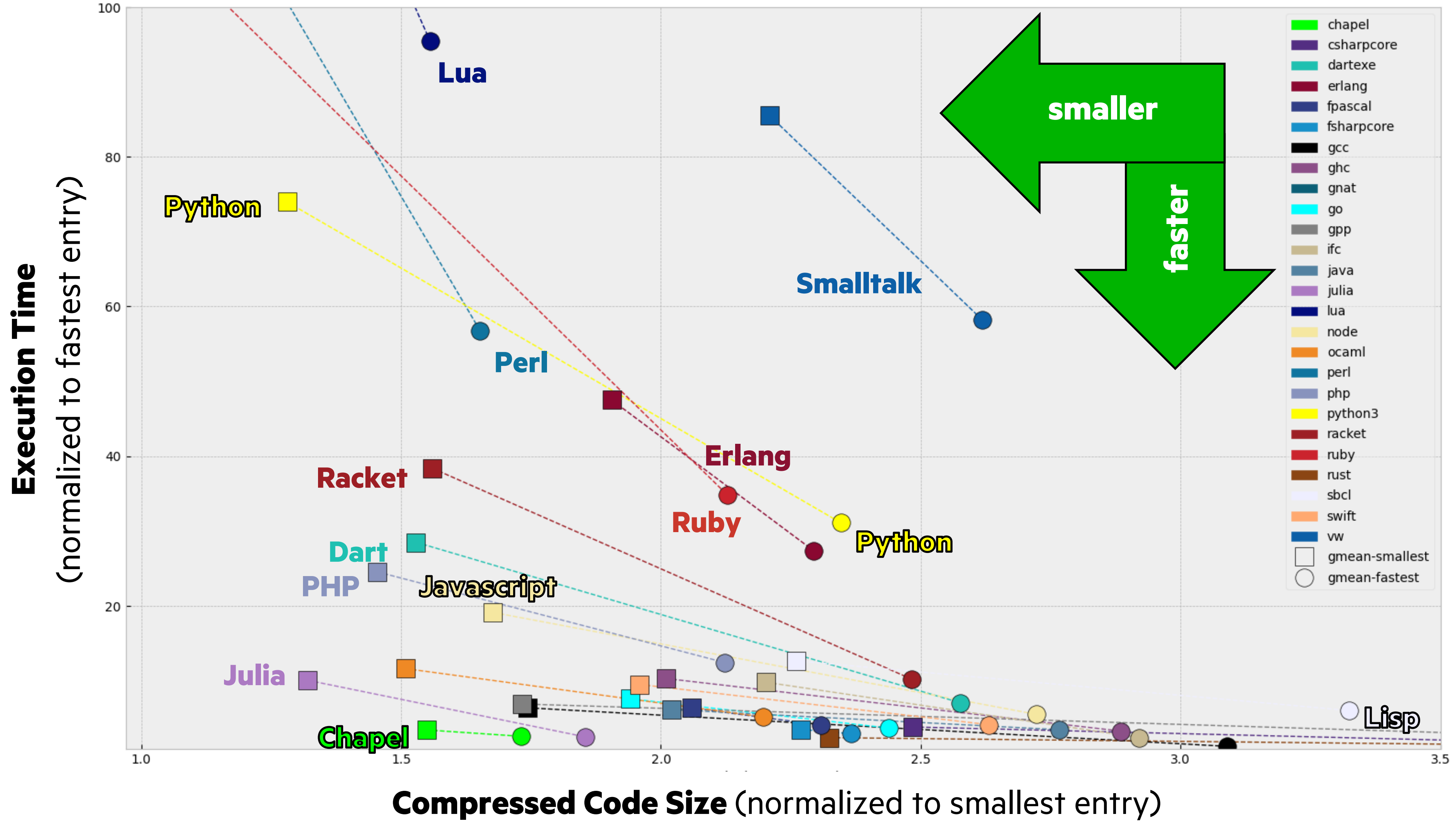


PERFORMANCE AND PRODUCTIVITY

How does Chapel compare to other languages?

CHAPEL IS COMPACT AND FAST

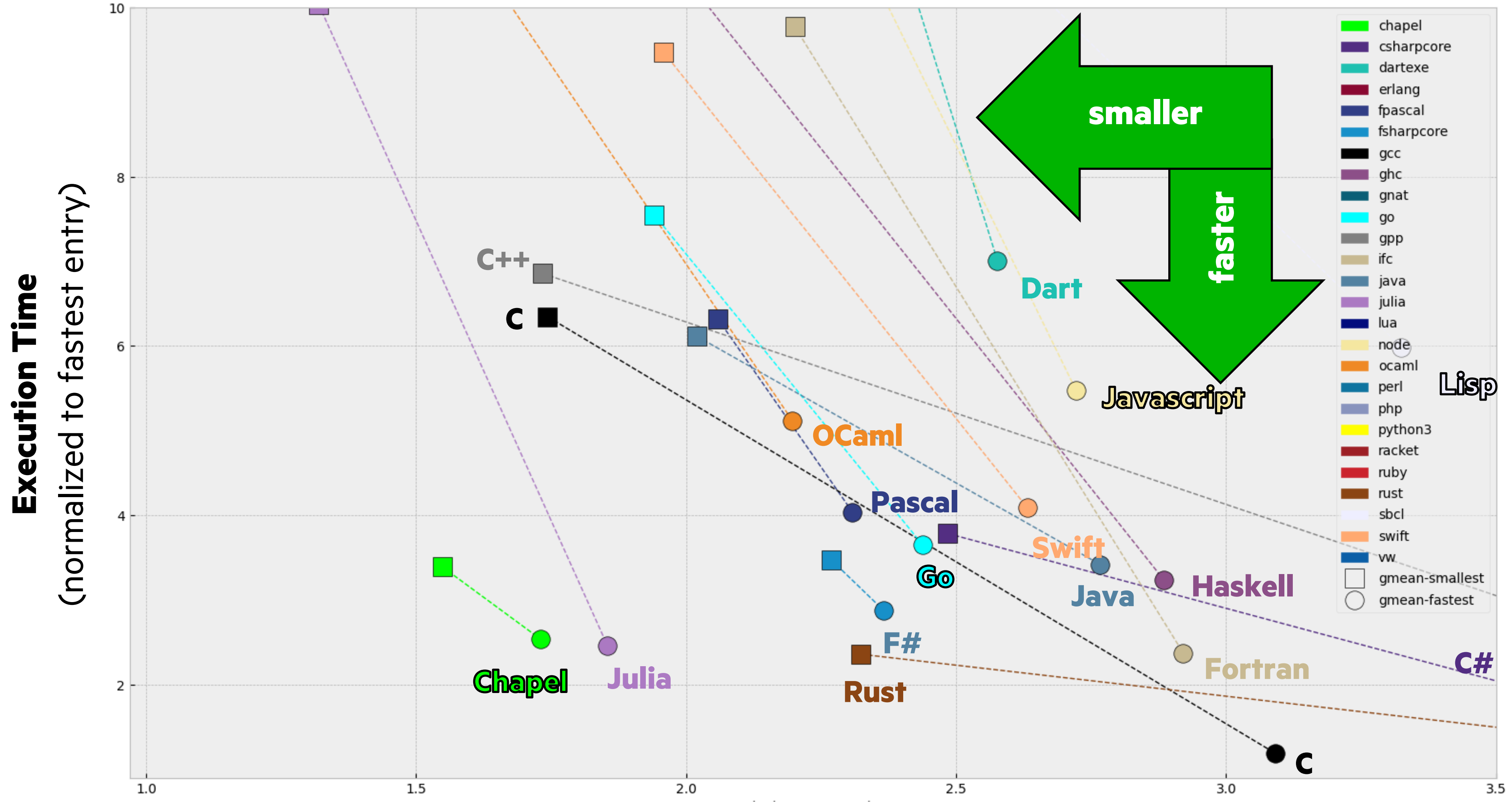
For Desktop Benchmarks



[plot generated by summarizing data from https://benchmarksgame-team.pages.debian.net/benchmarksgame/index.html as of Feb 8, 2023]

CHAPEL IS COMPACT AND FAST (ZOOMED)

For Desktop Benchmarks



Compressed Code Size (normalized to smallest entry)

[plot generated by summarizing data from https://benchmarksgame-team.pages.debian.net/benchmarksgame/index.html as of Feb 8, 2023]

ONE PUBLICATION MEASURING PRODUCTIVITY

- Gmys et al. [1] compared productivity and performance of several programming languages when implementing parallel metaheuristics for optimization problems
- Evaluated with a dual-socket, 32-core machine
- Result: Chapel more productive in terms of performance achieved vs. lines of code
  - vs Julia and Python+Numba

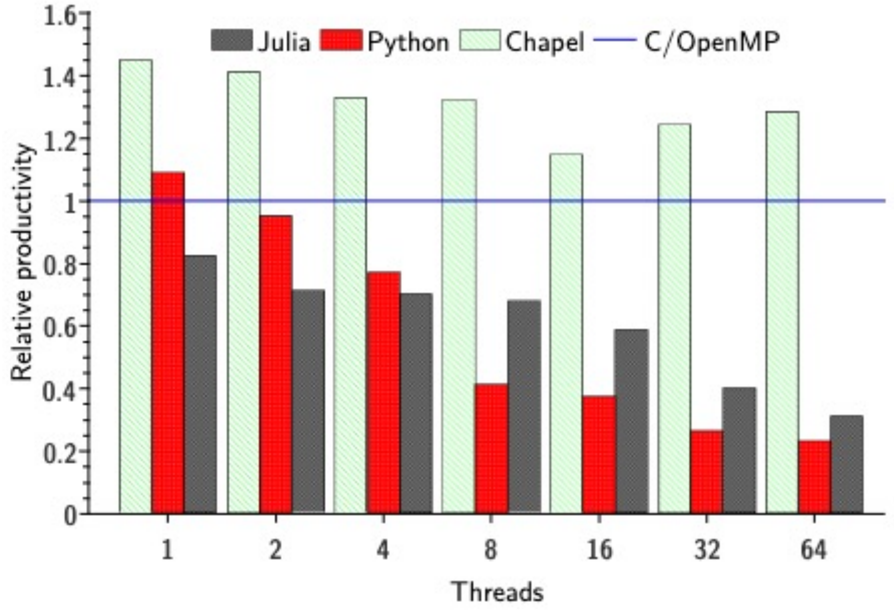


Figure 7: Relative productivity achieved by Chapel, Julia, and Python compared to the C/OpenMP reference. Results are given for the instance *nug22* and execution on 1 to 64 threads.

A figure from [1]

[1] Jan Gmys, Tiago Carneiro, Nouredine Melab, El-Ghazali Talbi, Daniel Tuyttens. A comparative study of high-productivity high-performance programming languages for parallel metaheuristics. Swarm and Evolutionary Computation, 2020, 57, 10.1016/j.swevo.2020.100720 . Available at https://inria.hal.science/hal-02879767

CHAPEL USERS

What do they say about it?

A Programming Language For Everybody

> *It's fast. Parallelization is really easy! I didn't know I could get so much from my desktop until I used it [Chapel].*

Nelson Luís Dias
Professor, Environmental Engineering Department, Federal University of Paraná (Brazil)
quote from his CHIUW 2022 talk [video]

Doing the Impossible

"

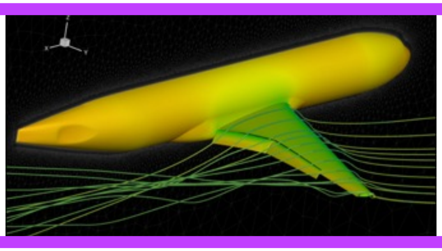
[Chapel] promotes programming efficiency … We ask students at the master's degree to do stuff that would take 2 years and they do it in 3 months.

Éric Laurendeau
Professor, Department of Mechanical Engineering, Polytechnique Montréal
quote from his 2021 CHIUW Keynote [video]

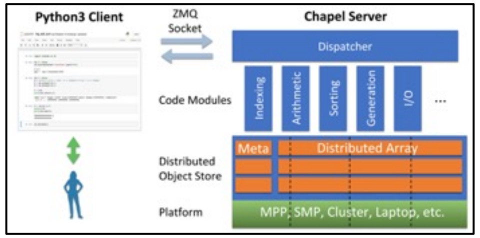
APPLICATIONS OF CHAPEL

Scaling to Solve Real Problems

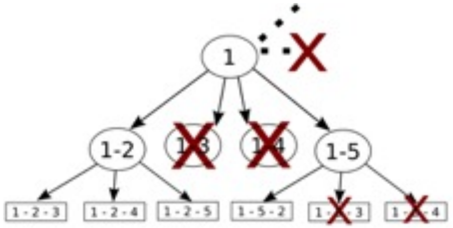
APPLICATIONS OF CHAPEL



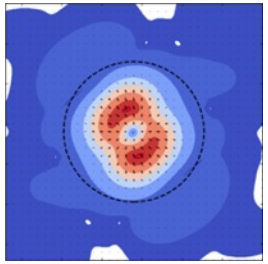
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



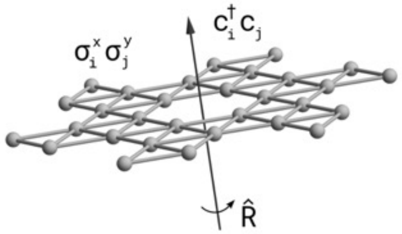
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



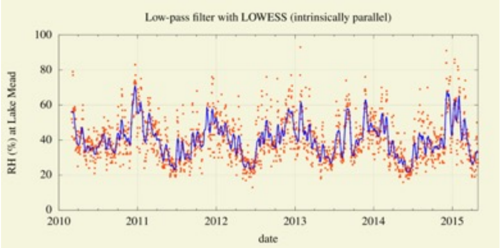
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



ChplUltra: Simulating Ultralight Dark Matter
Nikhil Padmanabhan, J. Luna Zagorac, et al.
Yale University et al.

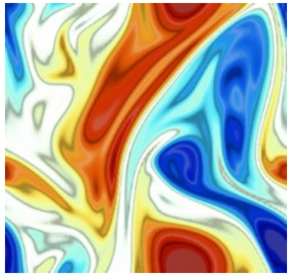


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

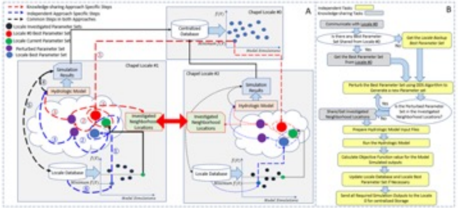


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

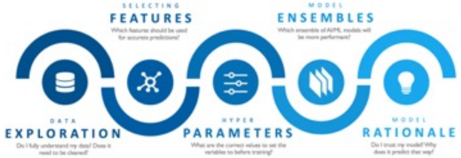
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



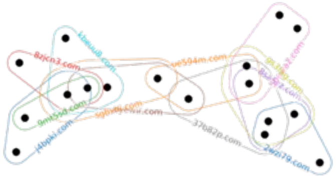
ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.



Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



CrayAI HyperParameter Optimization (HPO)
Ben Albrecht et al.
Cray Inc. / HPE



CHGL: Chapel Hypergraph Library
Louis Jenkins, Cliff Joslyn, Jesun Firoz, et al.
PNNL

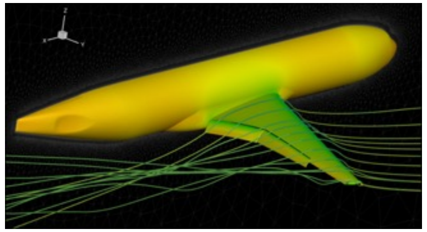
?

Your Application Here?

(images provided by their respective teams and used with permission)

CHAMPS SUMMARY

What is it?



- 3D unstructured CFD framework for airplane simulation
- ~85k lines of Chapel written from scratch in ~3 years

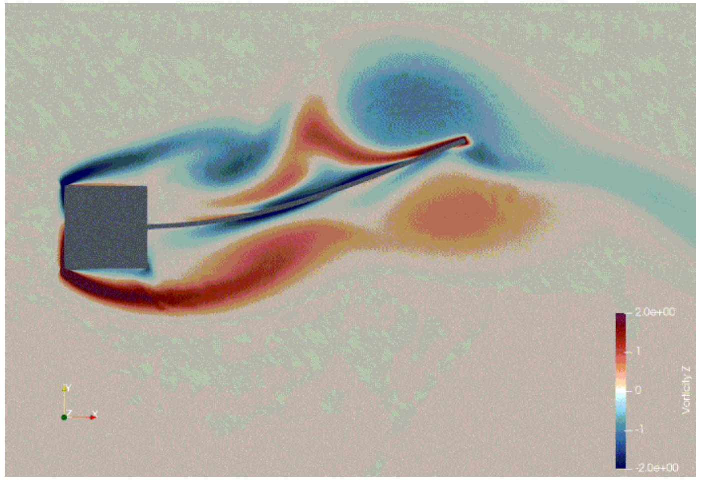
Who wrote it?

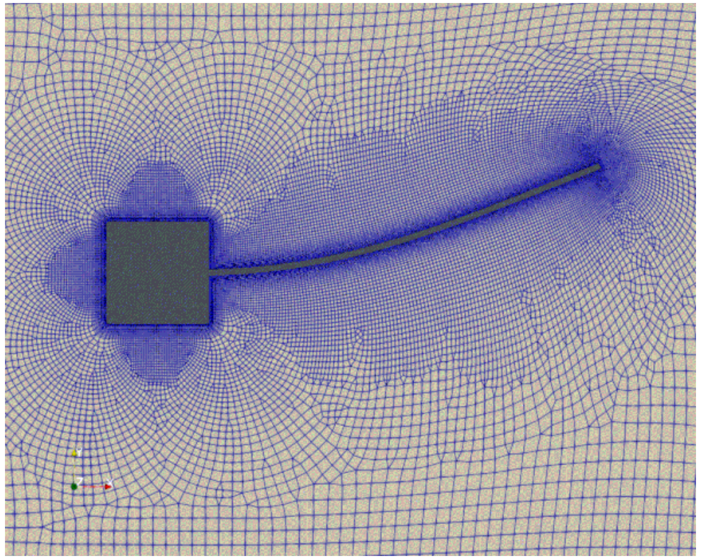
- Professor Éric Laurendeau's students + postdocs at Polytechnique Montreal

POLYTECHNIQUE MONTRÉAL

Why Chapel?

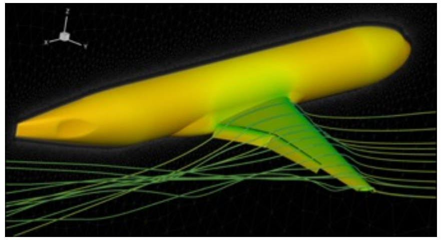
- performance and scalability competitive with MPI + C++
- students found it far more productive to use
- enabled them to compete with more established CFD centers



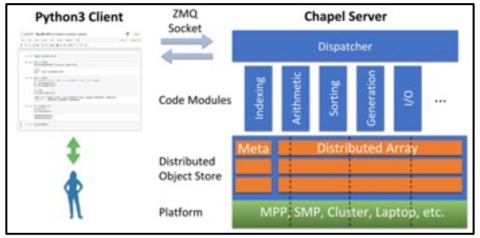


(images provided by the CHAMPS team and used with permission)

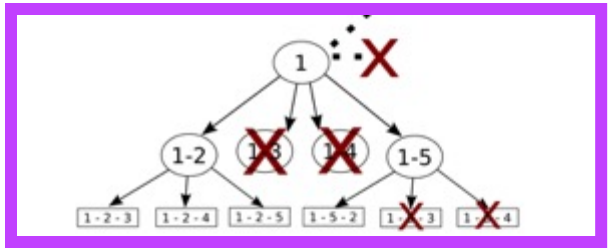
APPLICATIONS OF CHAPEL



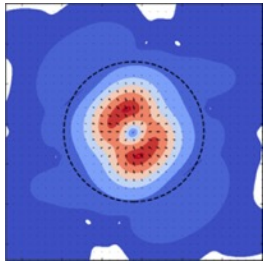
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



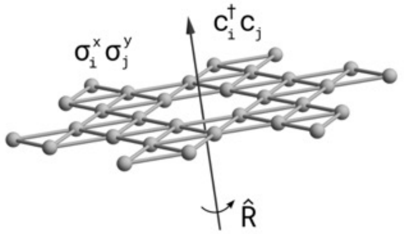
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



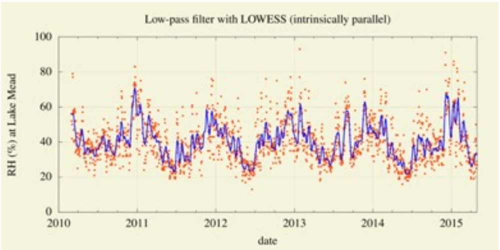
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



ChplUltra: Simulating Ultralight Dark Matter
Nikhil Padmanabhan, J. Luna Zagorac, et al.
Yale University et al.

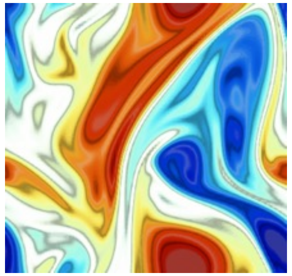


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

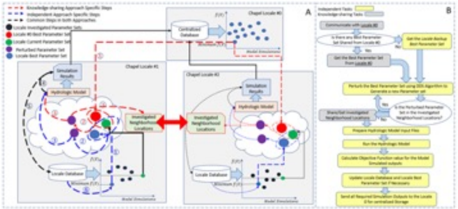


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

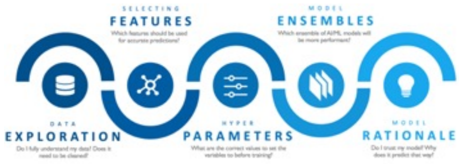
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



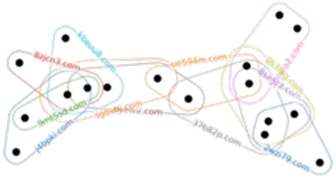
ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.



Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



CrayAI HyperParameter Optimization (HPO)
Ben Albrecht et al.
Cray Inc. / HPE



CHGL: Chapel Hypergraph Library
Louis Jenkins, Cliff Joslyn, Jesun Firoz, et al.
PNNL

?

Your Application Here?

(images provided by their respective teams and used with permission)

CHOP SUMMARY

What is it?

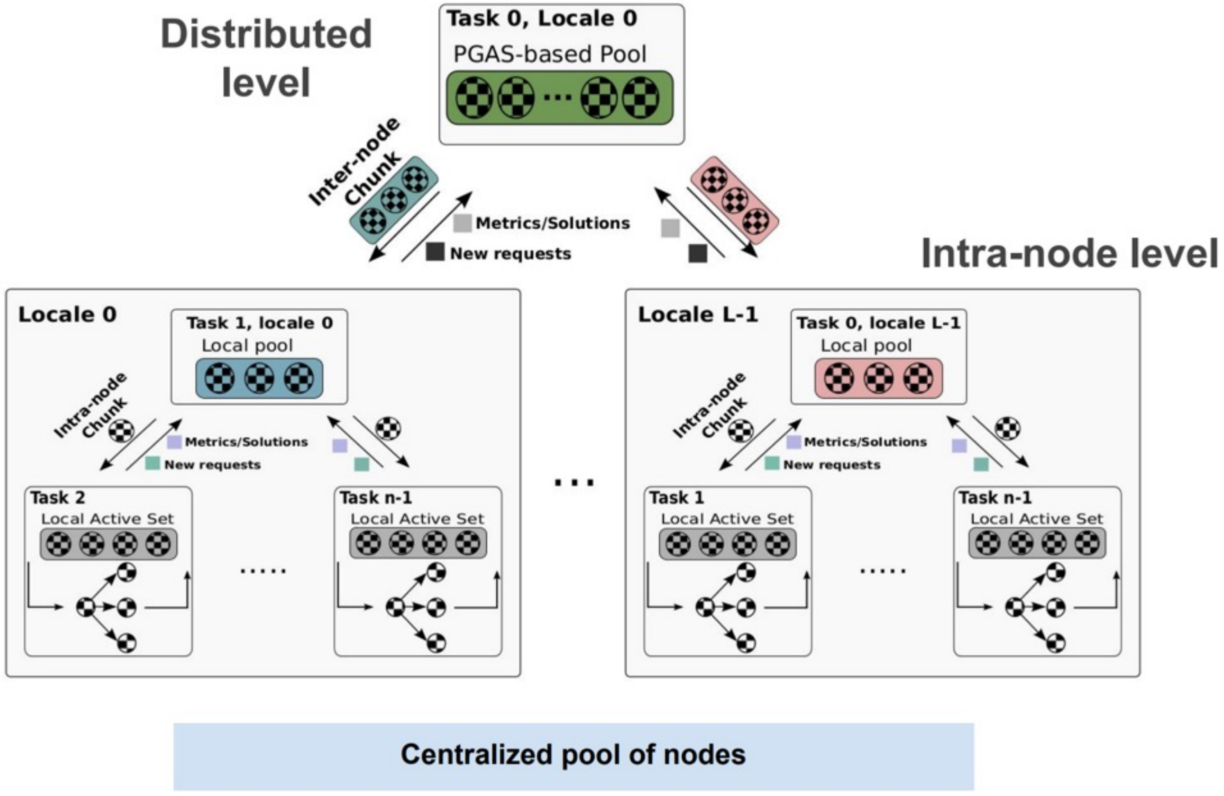
- Tree-based, branch and bound optimization algorithms
- irregular tree, lots of pruning

Who did it?

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

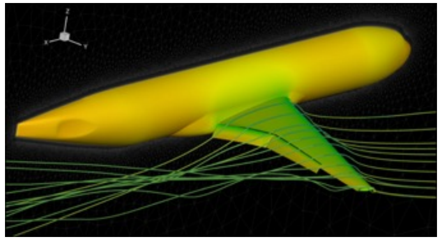
Why Chapel?

- Found Chapel to be more productive than alternatives
  - in the 2020 publication mentioned earlier
  - and in subsequent work

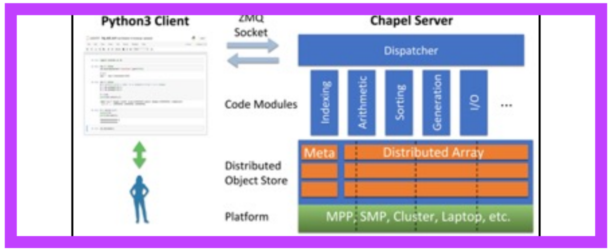


from slides for "Towards Ultra-scale Optimization Using Chapel" by Tiago Carneiro (University of Luxembourg) and Nouredine Melab (INRIA Lille), CHIUW 2021

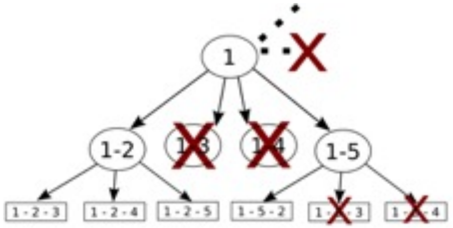
APPLICATIONS OF CHAPEL



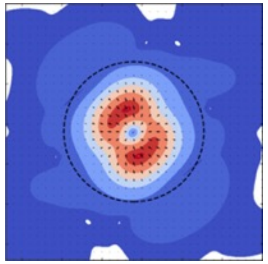
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



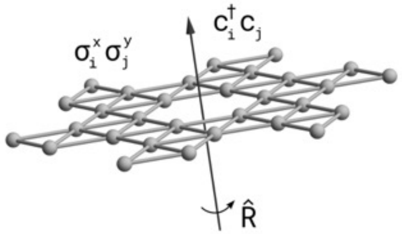
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



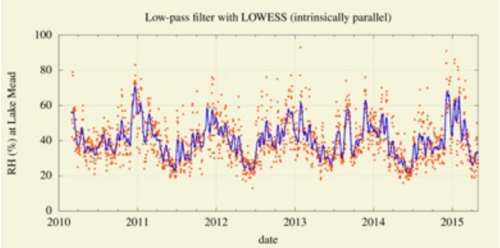
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



ChplUltra: Simulating Ultralight Dark Matter
Nikhil Padmanabhan, J. Luna Zagorac, et al.
Yale University et al.

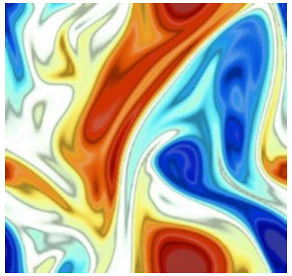


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

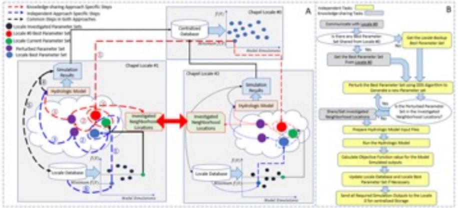


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

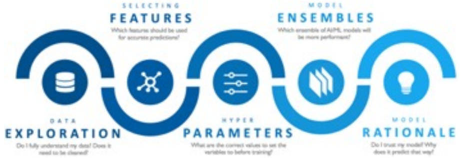
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



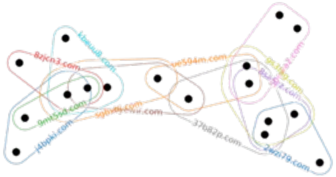
ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.



Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



CrayAI HyperParameter Optimization (HPO)
Ben Albrecht et al.
Cray Inc. / HPE



CHGL: Chapel Hypergraph Library
Louis Jenkins, Cliff Joslyn, Jesun Firoz, et al.
PNNL

?

Your Application Here?

(images provided by their respective teams and used with permission)

DATA SCIENCE IN PYTHON AT SCALE?

Motivation: Imagine you've got…

…HPC-scale data science problems to solve

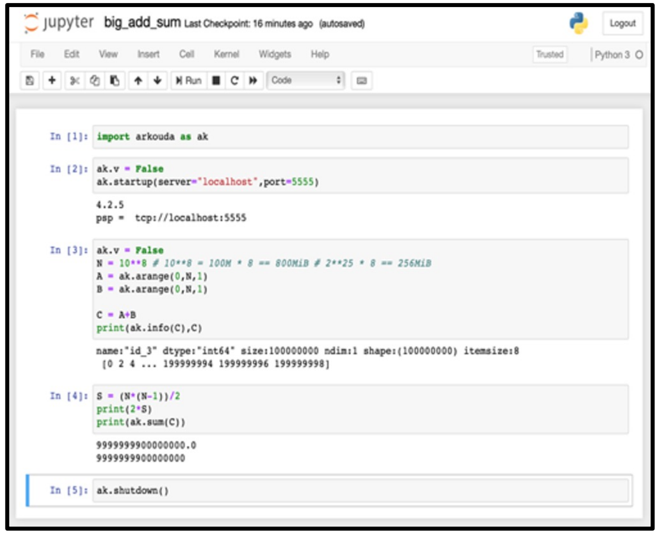
…a bunch of Python programmers

…access to HPC systems

How will you leverage your Python programmers to get your work done?

ARKOUDA: A PYTHON FRAMEWORK FOR INTERACTIVE HPC

Arkouda Client
(written in Python)



Arkouda Server
(written in Chapel)

User writes Python code in Jupyter, making familiar NumPy/Pandas calls

ARKOUDA SUMMARY

What is it?

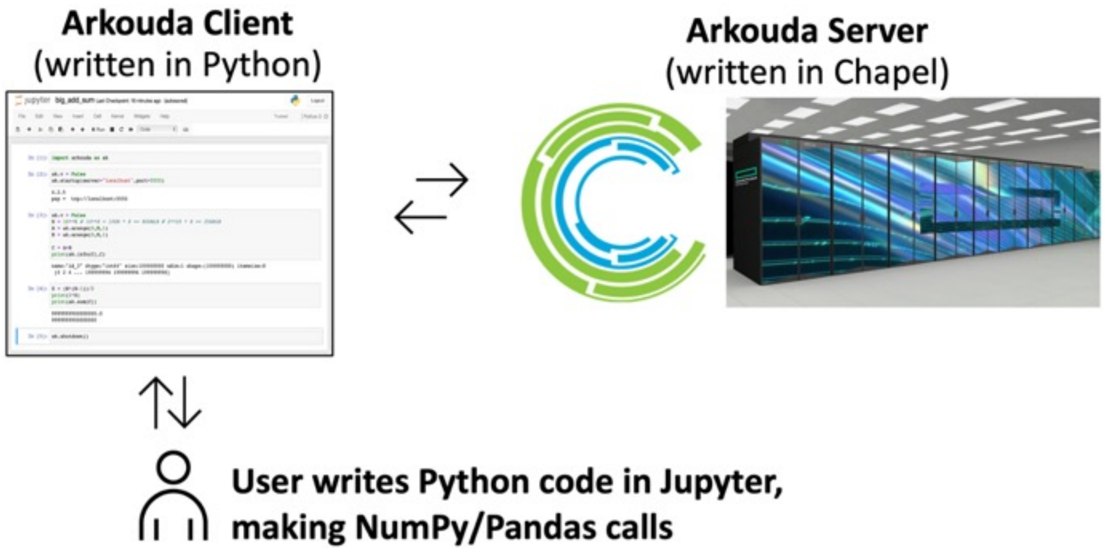
- A Python client-server framework supporting interactive supercomputing
  - Computes massive-scale results (TB-scale arrays) within the human thought loop (seconds to a few minutes)
  - Initial focus has been on a key subset of NumPy and Pandas for Data Science
- ~30k lines of Chapel + ~25k lines of Python, written since 2019
- Open-source: https://github.com/Bears-R-Us/arkouda

Who wrote it?

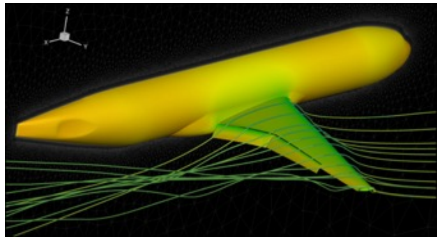
- Mike Merrill, Bill Reus, *et al.*, US DoD

Why Chapel?

- close to Pythonic
  - enabled writing Arkouda rapidly
  - doesn't repel Python users who look under the hood
- achieved necessary performance and scalability
- ability to develop on laptop, deploy on supercomputer

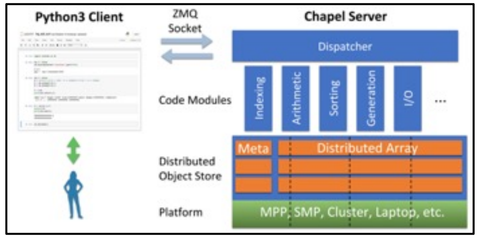


APPLICATIONS OF CHAPEL: LINKS TO USERS' TALKS (SLIDES + VIDEO)



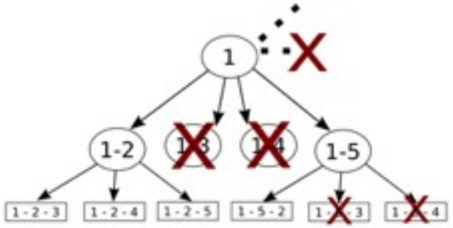
CHAMPS: 3D Unstructured CFD

CHIUW 2021 CHIUW 2022



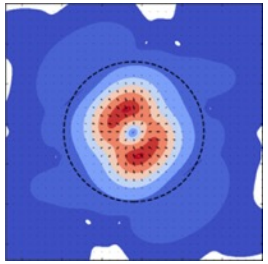
Arkouda: Interactive Data Science at Massive Scale

CHIUW 2020 CHIUW 2023



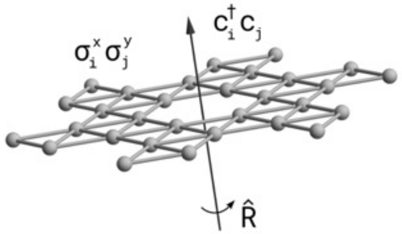
ChOp: Chapel-based Optimization

CHIUW 2021 CHIUW 2023



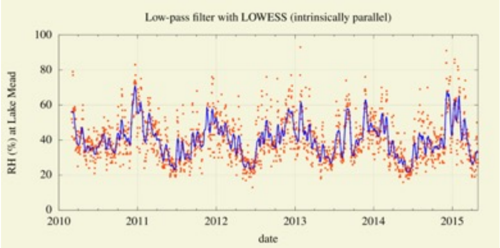
ChplUltra: Simulating Ultralight Dark Matter

CHIUW 2020 CHIUW 2022



Lattice-Symmetries: a Quantum Many-Body Toolbox

CHIUW 2022

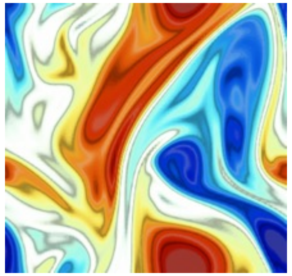


Desk dot chpl: Utilities for Environmental Eng.

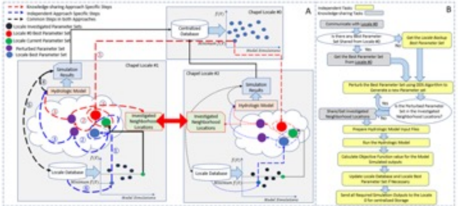
CHIUW 2022

RapidQ: Mapping Coral Biodiversity

CHIUW 2023

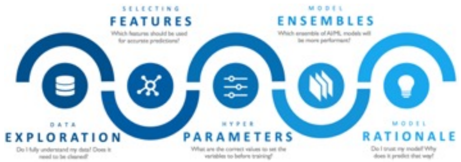


ChapQG: Layered Quasigeostrophic CFD



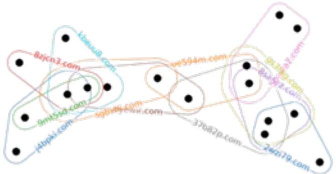
Chapel-based Hydrological Model Calibration

CHIUW 2023



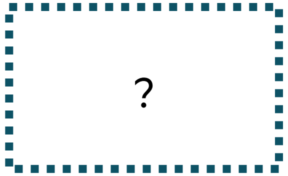
CrayAI HyperParameter Optimization (HPO)

CHIUW 2021



CHGL: Chapel Hypergraph Library

CHIUW 2020



Your Application Here?

(images provided by their respective teams and used with permission)

DEMOS

WRAP-UP

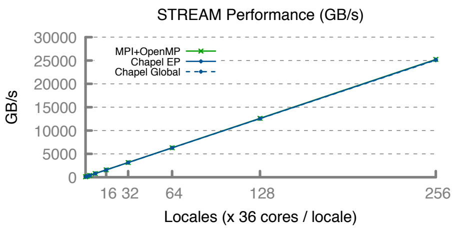
THE CHAPEL TEAM AT HPE

SUMMARY

Chapel is unique among programming languages

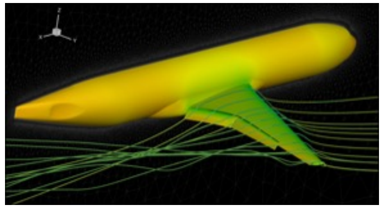
- built-in features for scalable parallel computing make it HPC-ready
- supports clean, concise code relative to conventional approaches
- ports and scales from laptops to supercomputers

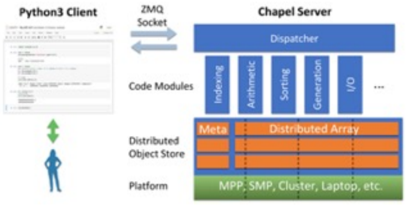
```
use BlockDist;

config const n = 1_000_000,
             alpha = 0.01;

const Dom = Block.createDomain({1..n});
var A, B, C: [Dom] real;

B = 2.0;
C = 1.0;

A = B + alpha * C;
```



Chapel is being used for productive parallel computing at scale

- users are reaping its benefits in practical, cutting-edge applications
- in diverse application domains: from physical simulation to data science
- scaling to thousands of nodes / millions of processor cores





Vendor-neutral GPU support is maturing rapidly

- fleshes out an overdue aspect of “any parallel hardware”

```
coforall gpu in here.gpus do on gpu {
  var A, B, C: [1..n] real;
  A = B + alpha * C;
}
```

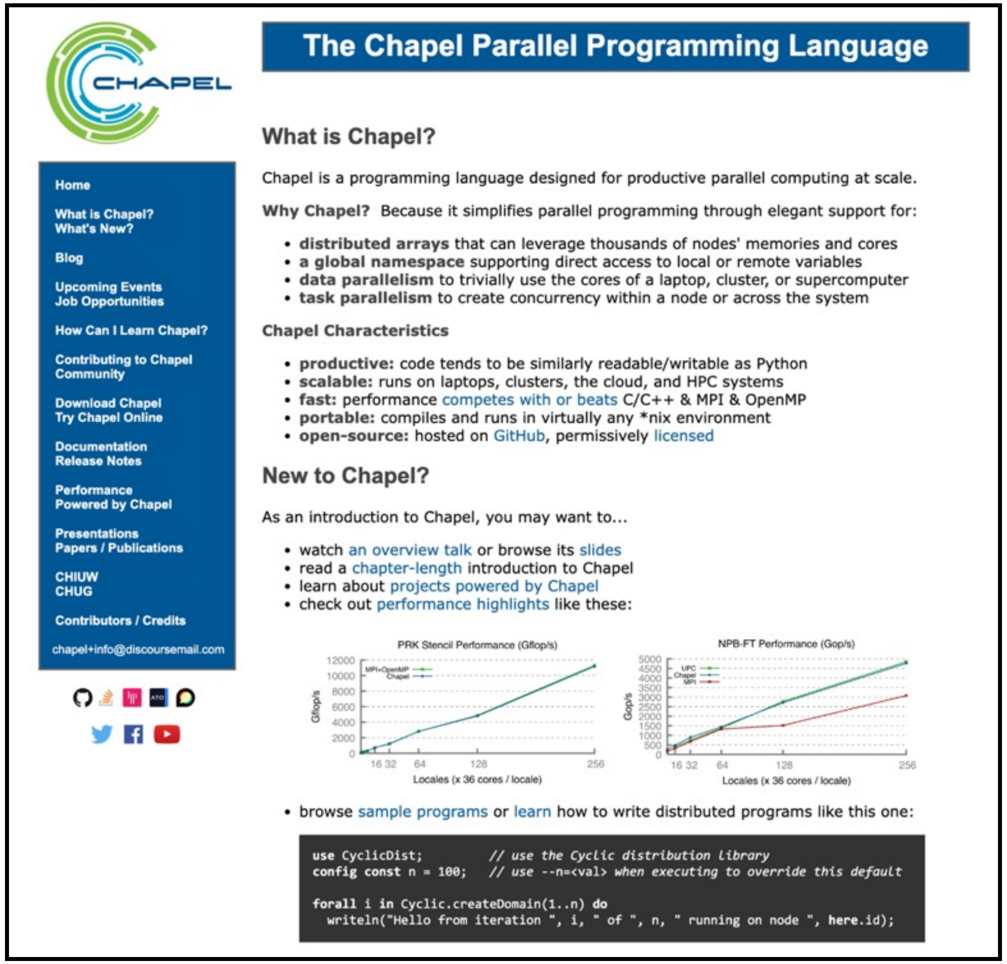
We’re interested in helping new users and fostering new collaborations

CHAPEL RESOURCES

Chapel homepage: https://chapel-lang.org
- (points to all other resources)

Social Media:
- Blog: https://chapel-lang.org/blog/
- Twitter: @ChapelLanguage
- Facebook: @ChapelLanguage
- YouTube: @ChapelLanguage

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

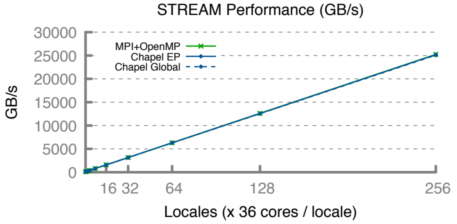


SUMMARY

Chapel is unique among programming languages

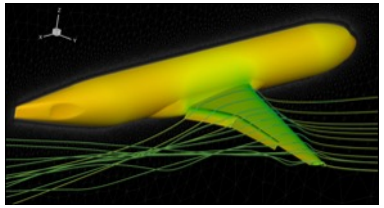
- built-in features for scalable parallel computing make it HPC-ready
- supports clean, concise code relative to conventional approaches
- ports and scales from laptops to supercomputers

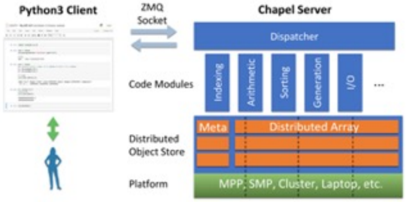
```
use BlockDist;

config const n = 1_000_000,
             alpha = 0.01;

const Dom = Block.createDomain({1..n});
var A, B, C: [Dom] real;

B = 2.0;
C = 1.0;

A = B + alpha * C;
```



Chapel is being used for productive parallel computing at scale

- users are reaping its benefits in practical, cutting-edge applications
- in diverse application domains: from physical simulation to data science
- scaling to thousands of nodes / millions of processor cores





Vendor-neutral GPU support is maturing rapidly

- fleshes out an overdue aspect of “any parallel hardware”

```
coforall gpu in here.gpus do on gpu {
  var A, B, C: [1..n] real;
  A = B + alpha * C;
}
```

We’re interested in helping new users and fostering new collaborations

THANK YOU

https://chapel-lang.org
@ChapelLanguage