Hewlett Packard
Enterprise

CHIUW 2023: STATE OF THE CHAPEL PROJECT

Brad Chamberlain

June 2, 2023

WELCOME TO THE 10TH ANNUAL CHIUW WORKSHOP!

CHIUW 2014

Can a single parallel language be …

… as productive as Python?

… as fast as Fortran?

… as scalable as MPI?

Attend CHIUW on Friday and hear about how the Chapel community is working to make this vision a reality!

Introduction to Chapel, State of the Project	
8:30 - 9:00:	Brad Chamberlain, *Cray Inc.*
Technical Talks: Application Studies	
9:00 - 9:30:	User Experiences with a Chapel Implementation of UTS
	Claudia Fohry (*Universität Kassel, Germany*), Jens Breitbart (*Technische Universität München, Germany*)
9:30 - 10:00:	Evaluating Next Generation PGAS Languages for Computational Chemistry
	Daniel Chavarria-Miranda, Sriram Krishnamoorthy, Joseph Manzano, Abhinav Vishnu (*Pacific Northwest National Laboratory*)
10:00 - 10:30:	**Break**
Technical Talks: Language Extensions	
10:30 - 11:00:	Programmer-Guided Reliability in Chapel
	David E. Bernholdt, Wael R. Elwasif, Christos Kartsaklis, Seyong Lee, Tiffany M. Mintz (*Oak Ridge National Laboratory*)
11:00 - 11:30:	Towards Interfaces for Chapel
	Chris Wailes, Jeremy G. Siek (*Indiana University*)
Technical Talks: Compiler Optimizations	
11:30 - 12:00:	Affine Loop Optimization using Modulo Unrolling in Chapel
	Argon Sharma, Rajeev Barua (*University of Maryland*), Michael Ferguson (*Laboratory for Telecommunication Sciences*)
12:00 - 1:00:	**Lunch** (on your own)
Invited Talk: Robert Harrison	
1:00 - 1:45:	**Walking to the Chapel**
	Robert Harrison (*Stony Brook University/Brookhaven National Laboratory*)
	Abstract: MADNESS is a general-purpose numerical environment that sits upon a scalable runtime that consciously includes elements "borrowed" from other projects including Charm++ and the HPCS programming languages, including Chapel; it is also designed to be interoperable with "legacy" code. But as I have said to Chapel's architects several times, maintaining our own runtime is just an unpleasant transitional phase and we are looking for a permanent home—is that home Chapel? I'll give you some flavor of what MADNESS does and how, with the objective of starting a conversation and seeding collaborations.
Technical Talks: Compiler Optimizations (continued)	
1:45 - 2:15:	LLVM Optimizations for PGAS Programs
	Akihiro Hayashi, Rishi Surendran, Jisheng Zhao, Vivek Sarkar (*Rice University*), Michael Ferguson (*Laboratory for Telecommunication Sciences*)
Technical Talks: Runtime Improvements	
2:15 - 2:45:	Opportunities for Integrating Tasking and Communication Layers
	Dylan T. Stark, Brian W. Barrett (*Sandia National Laboratories*)
2:45 - 3:15:	Caching in on Aggregation
	Michael Ferguson (*Laboratory for Telecommunication Sciences*)
3:15 - 3:30:	**Break**
Community/Panel Discussion	
3:30 - 4:30:	Anyone who is interested

CHIUW: Chapel Implementers and Users Workshop

http://chapel.cray.com/CHIUW.html

Friday, May 23rd, 2014

Advance Program

The Chapel Implementers and Users Workshop, to be held in conjunction with IPDPS 2014, will be the first in what is anticipated to be an annual series of workshops designed to bring developers and users of the Chapel language (http://chapel.cray.com) together to report on work being done with the language across the broad open-source community. Attendance is open to anyone interested in Chapel, from the most seasoned Chapel user or developer to someone simply curious to learn more. On behalf of the Chapel community and CHIUW steering committee, we hope to see you at CHIUW!

WELCOME TO THE 10TH ANNUAL CHIUW WORKSHOP!

CHIUW 2

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Workshop

with IPDPS 2014, will
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Attendance is open to
er to someone simply

On this day

9 years ago

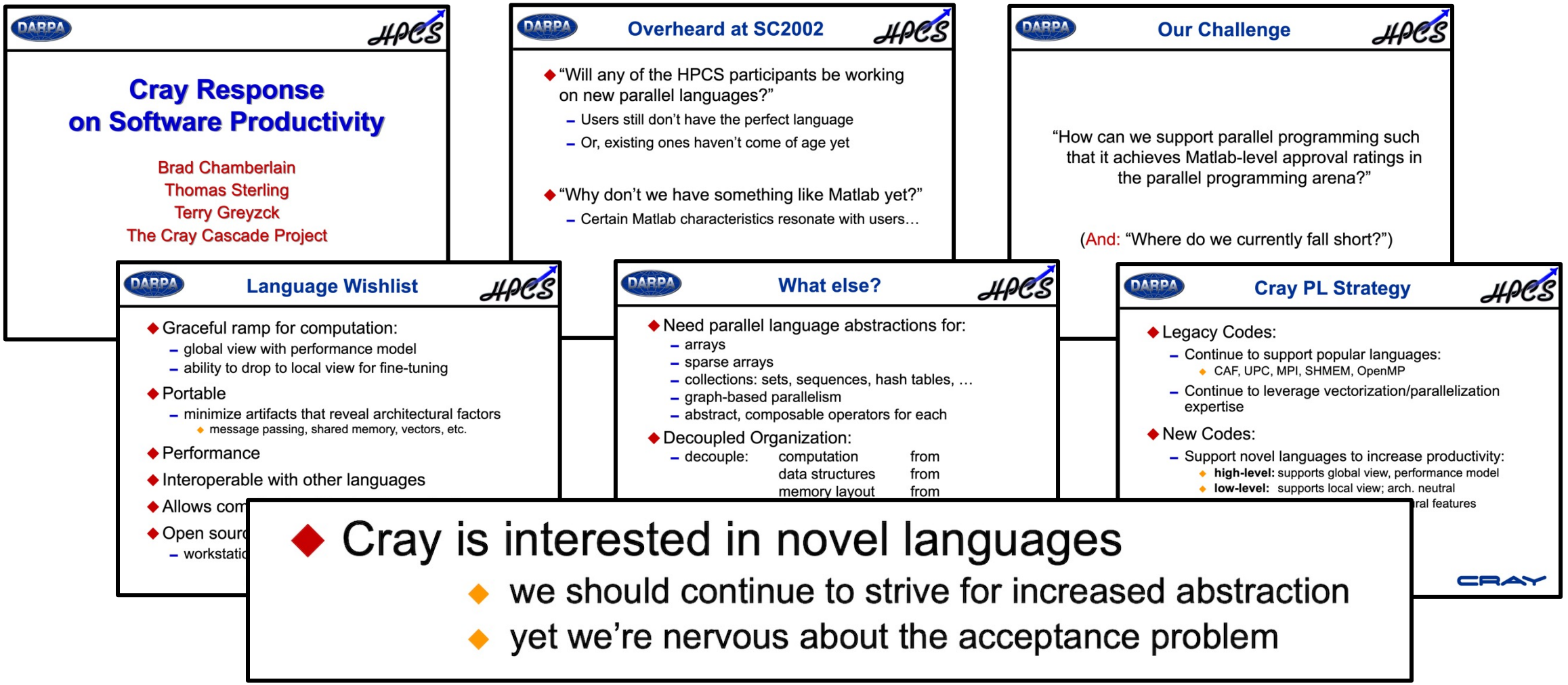
Brad Chamberlain is with **Lydia Duncan**.
May 23, 2014 ·

still had a solid crowd at the end of a workshop on Chapel at the end of a week-long conference. Not a bad way to kick off what we intend to be an annual event.

http://chapel.cray.com/CHIUW.html

CHAPEL'S TURNING 20?!?

Cray first expressed its intention of developing new language(s) as part of HPCS in January 2003



(slides excerpted from a presentation at HPCS Software Productivity Workshop, January 16, 2003)

WHAT IS CHAPEL?

Chapel: A modern parallel programming language

- portable & scalable
- open-source & collaborative

Goals:

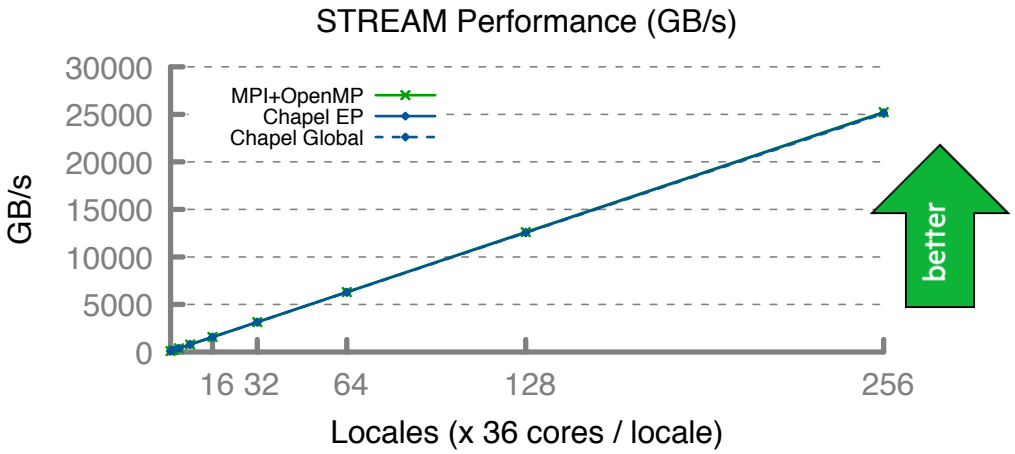
- Support general parallel programming
- Make parallel programming at scale far more productive

HPC BENCHMARKS: CONVENTIONAL APPROACHES VS. CHAPEL

STREAM TRIAD: C + MPI + OPENMP

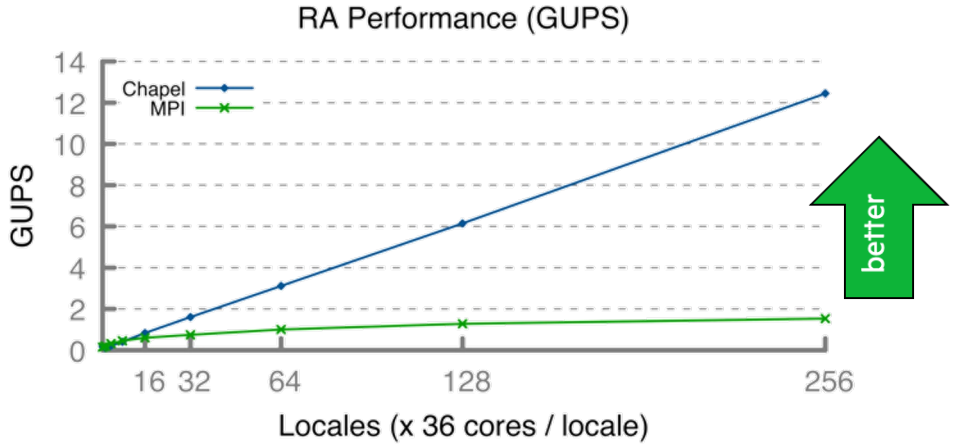
```
#include <hpcc.h>
#ifdef _OPENMP
#include <omp.h>
#endif

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 );
```

```
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;
```

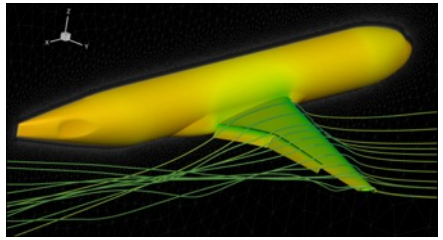


HPCC RA: MPI KERNEL

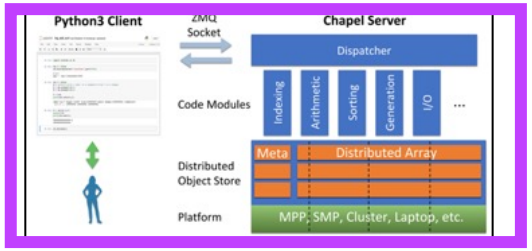
```
…
forall (_, r) in zip(Updates, RAStream()) do
  T[r & indexMask].xor(r);
…
```



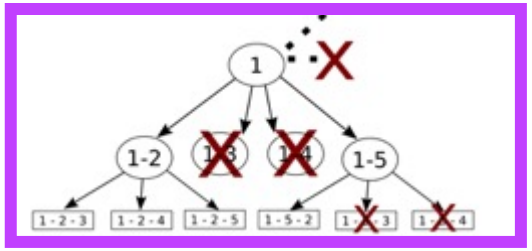
APPLICATIONS OF CHAPEL



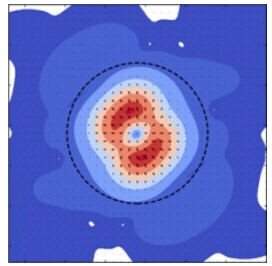
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



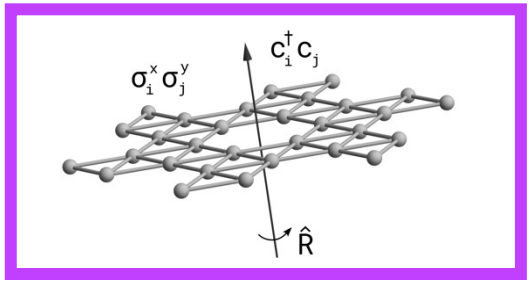
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



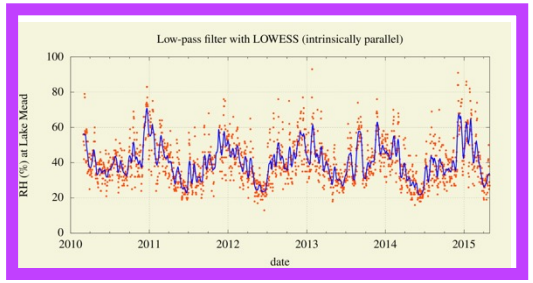
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



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

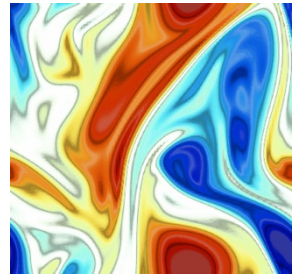


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

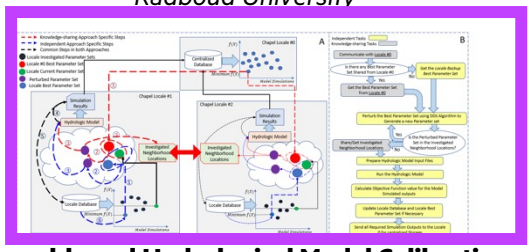


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

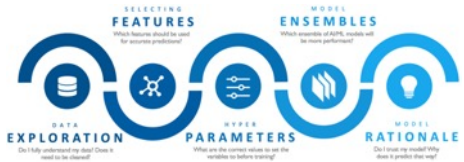
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



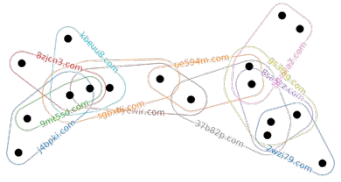
ChapQG: Layered Quasigeostrophic CFD
Ian Grooms and Scott Bachman
University of Colorado, Boulder et al.



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



CrayAI HyperParameter Optimization (HPO)



CHGL: Chapel Hypergraph Library

?

Your Application Here?

Much more about Applications of Chapel throughout the day

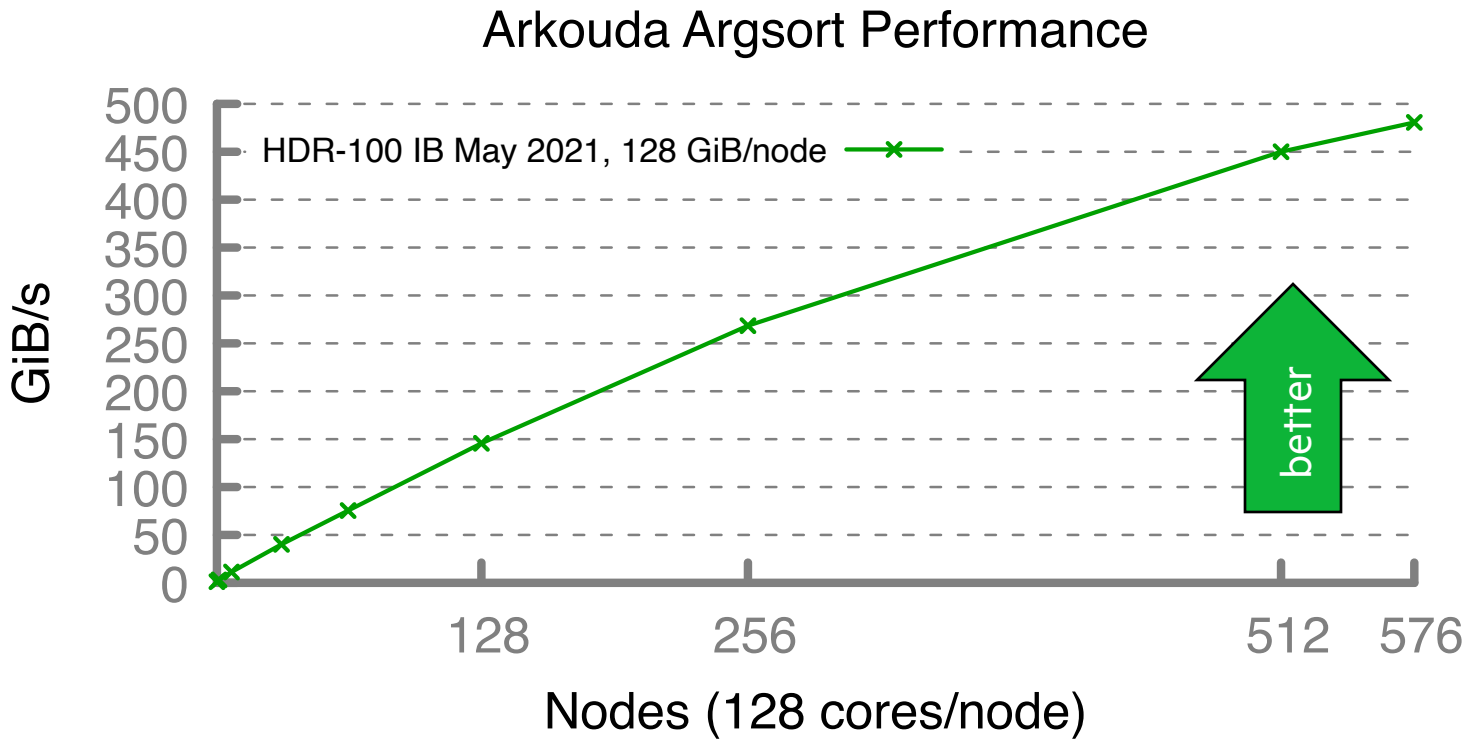
(images provided by their respective teams and used with permission)

CHAPEL ON
HPE CRAY EX / SLINGSHOT-11

ARKOUDA ARGSORT PERFORMANCE: CHIUW 2022

HPE Apollo (May 2021)

- HDR-100 Infiniband network (100 Gb/s)
- 73,728 cores / 576 nodes
- 72 TiB of 8-byte values
- ~480 GiB/s (~150 seconds)



A notable performance achievement in ~100 lines of Chapel

ARKOUDA ARGSORT PERFORMANCE: TODAY

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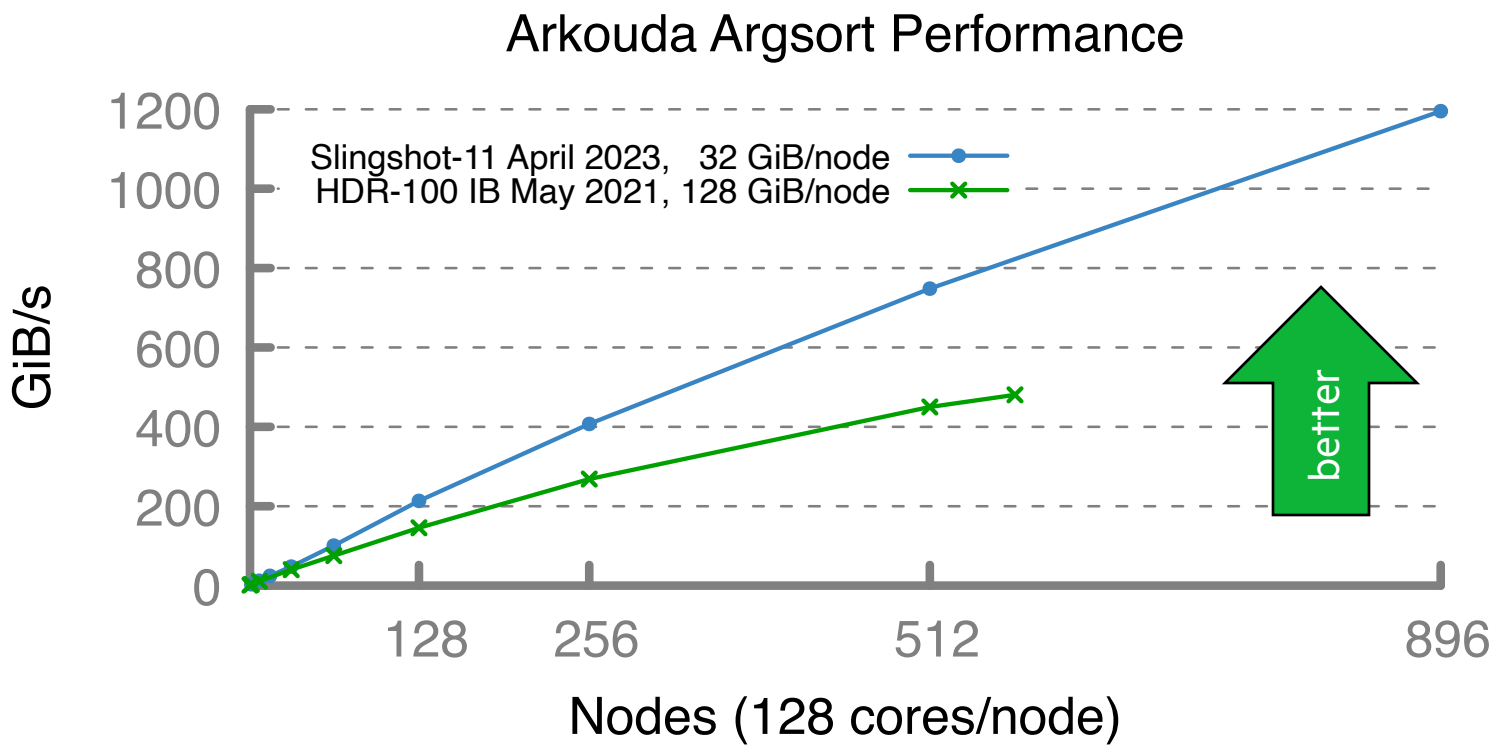
HPE Cray EX (April 2023)

- Slingshot-11 network (200 Gb/s)
- 114,688 cores / 896 nodes
- 28 TiB of 8-byte values
- ~1200 GiB/s (~24 seconds)



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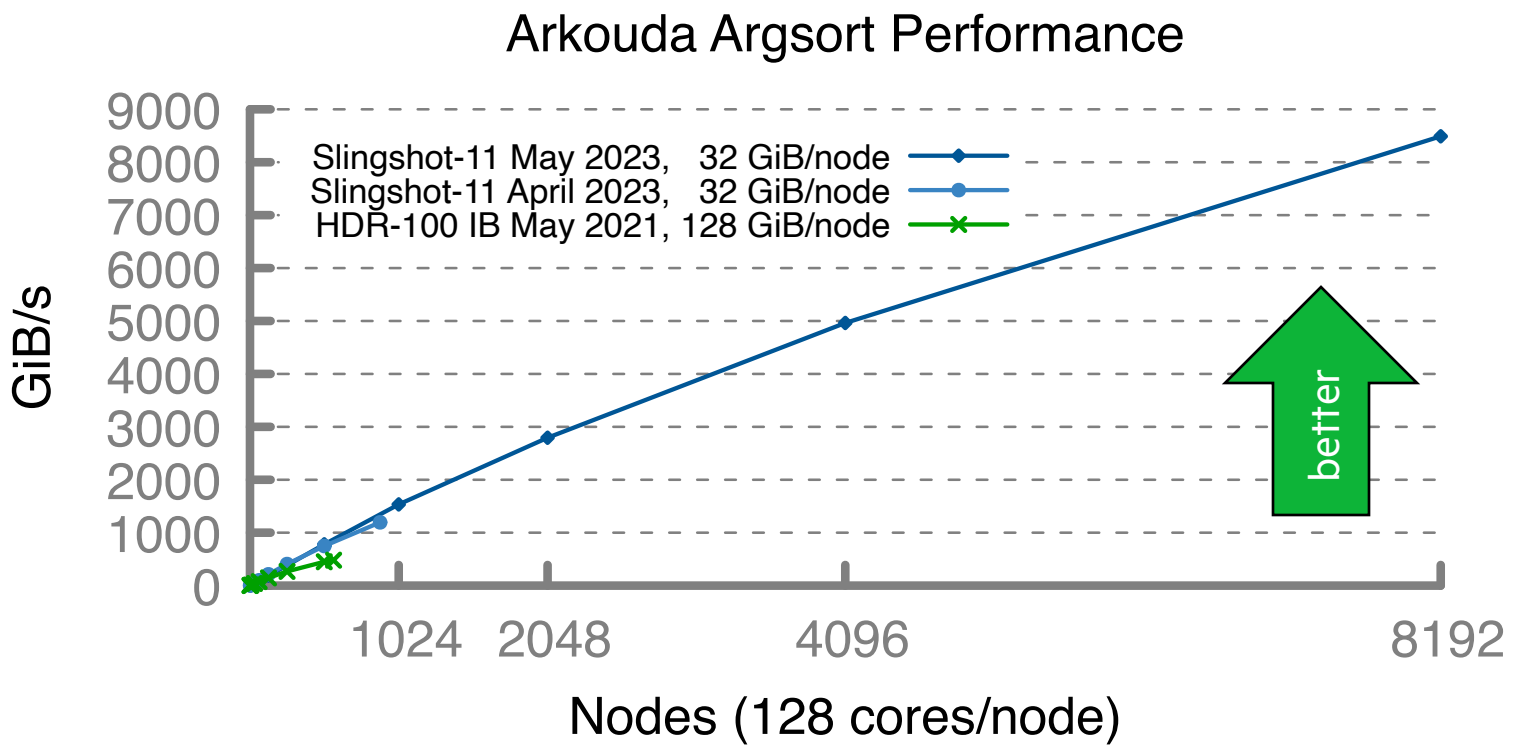
HPE Cray EX (May 2023)

- Slingshot-11 network (200 Gb/s)
- 1,048,576 cores / 8192 nodes
- 256 TiB of 8-byte values
- ~8500 GiB/s (~31 seconds)



A notable performance achievement in ~100 lines of Chapel

HPE CRAY EX IMPROVEMENTS

Other New Features on HPE Cray EX:

- ability to run multiple locales per compute node
  - locale per NIC
  - locale per socket
- ability to devote a core to handling communication

What's Next?

- Extend the above features to other platforms
  - most notably GASNet over InfiniBand
- Perform additional benchmarking studies at scale (HPCC, Bale, PRK, …)
  - comparing to reference versions in MPI and SHMEM

DYNO:
REVAMPING THE CHAPEL COMPILER

DYNO IN A NUTSHELL

Motivation:

- The Chapel compiler was originally written quickly, by a small team, as a research project
- As a result, it tends to be…

  …slow

  …difficult to understand when there are errors

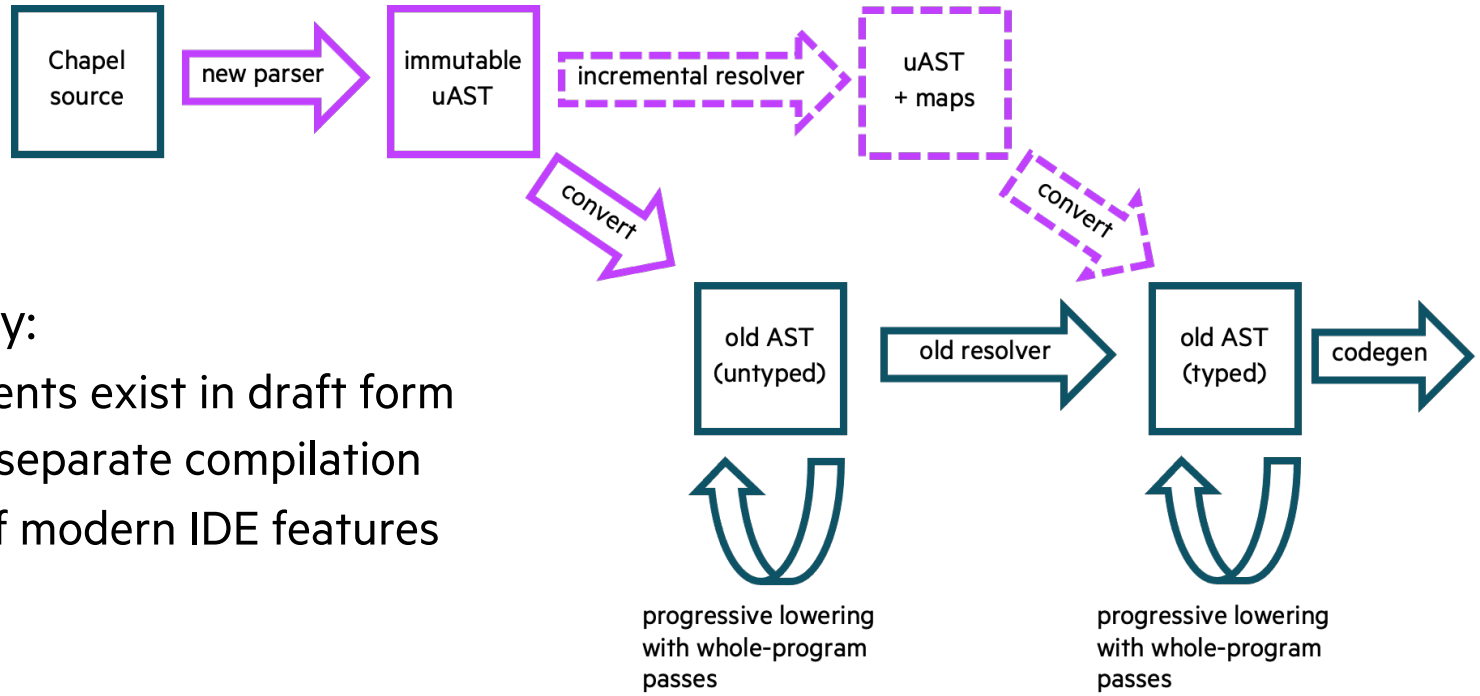
  …not terribly well-architected: inflexible, challenging to get started with

This Effort:

- Last year, we kicked off an effort to massively rearchitect it, to address these lacks:
  - better user experience in terms of speed and errors
  - easier for developers to start contributing to
  - more flexible and capable:
    - separate compilation / incremental recompilation
    - better support for tools
    - dynamic evaluation of code
    - …

DYNO HIGHLIGHTS SINCE CHIUW 2022

- Key elements of 'dyno' are now used in the Chapel release:
  - **1.27.0:** its parser and AST became the default
  - **1.28.0:** 'chpldoc' was rewritten to use its front-end library
  - **1.29.0:** its framework for improved error messages came online
  - **'main':** its scope resolver is now used by default (and will be in this month's 1.31.0 release)



- Other key elements are well underway:
  - **type/call resolver:** the major components exist in draft form
  - **AST save/restore:** a key step toward separate compilation
  - **Chapel language server:** in support of modern IDE features

COMPILING CHAPEL TO GPUS

STREAM TRIAD USING GPUS AND CPUS: CHIUW 2022 (SINGLE-LOCALE)

stream-ep.chpl

```
config const n = 1_000_000,
             alpha = 0.01;


  cobegin {
    coforall gpuid in 1..numGPUs do on here.getChild(gpuid) {
      var A, B, C: [1..n] real;
      A = B + alpha * C;
    }
    {
      var A, B, C: [1..n] real;
      A = B + alpha * C;
    }
  }
```

'cobegin { ... }' creates a task per child statement

one task creates GPU tasks

the other runs the multi-CPU triad

This program uses all CPUs and GPUs on a single compute node

STREAM TRIAD USING GPUS AND CPUS: TODAY (SINGLE-LOCALE)

stream-ep.chpl

```
config const n = 1_000_000,
             alpha = 0.01;


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

Improved syntax for GPU sublocales

This program uses all CPUs and GPUs on a single compute node

STREAM TRIAD USING GPUS AND CPUS: TODAY (MULTI-LOCALE)

stream-ep.chpl

```
config const n = 1_000_000,
             alpha = 0.01;

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

Support for multi-locale GPU programs

This program uses all CPUs and GPUs across *all* of our compute nodes

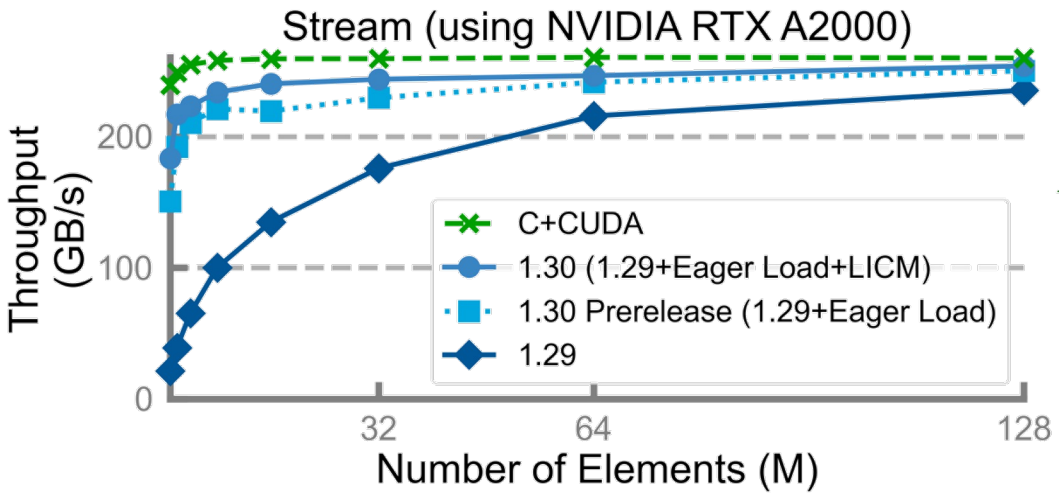
CHAPEL ON GPUS: PROGRESS SINCE CHIUW 2022

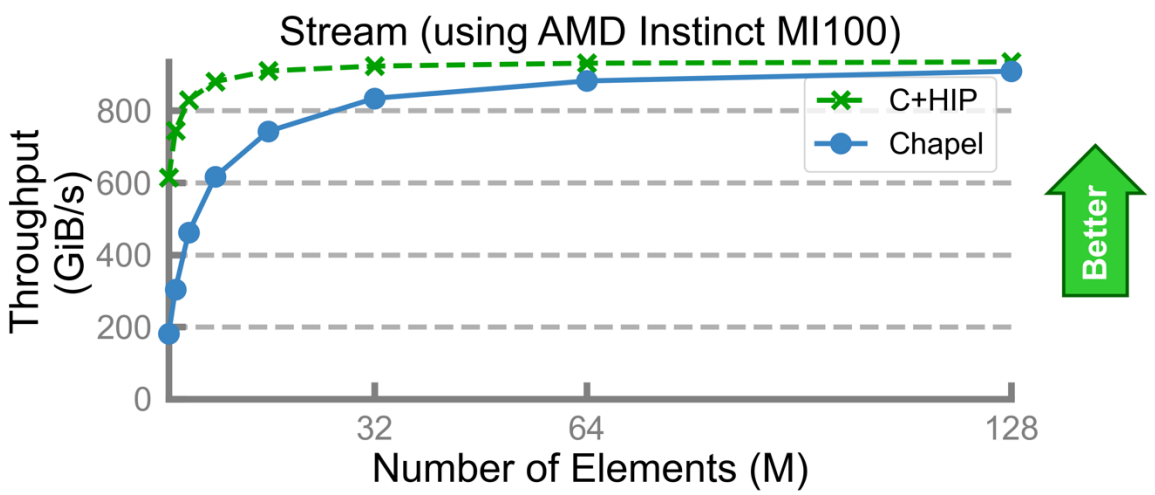
Status: Lots of progress in the past year:

- **Mar 2022** (v1.26): first multi-GPU NVIDIA runs
- **CHIUW 2022**
- **Jun 2022** (v1.27): first multi-locale, multi-GPU NVIDIA runs
- **Dec 2023** (v1.29): first heroic AMD runs
- **Mar 2023** (v1.30): first multi-GPU AMD runs
- **Jun 2023** (v1.31): first multi-locale, multi-GPU AMD runs

} Throughout this time, ongoing improvements in generality, features, and performance

STREAM TRIAD: GPU PERFORMANCE VS. REFERENCE VERSIONS





Performance vs. reference versions has become increasingly competitive over the past 6 months

More about GPU Computing with Chapel in Session 5 today (1:35 PDT)

LANGUAGE AND LIBRARIES

CHAPEL 2.0

Background:

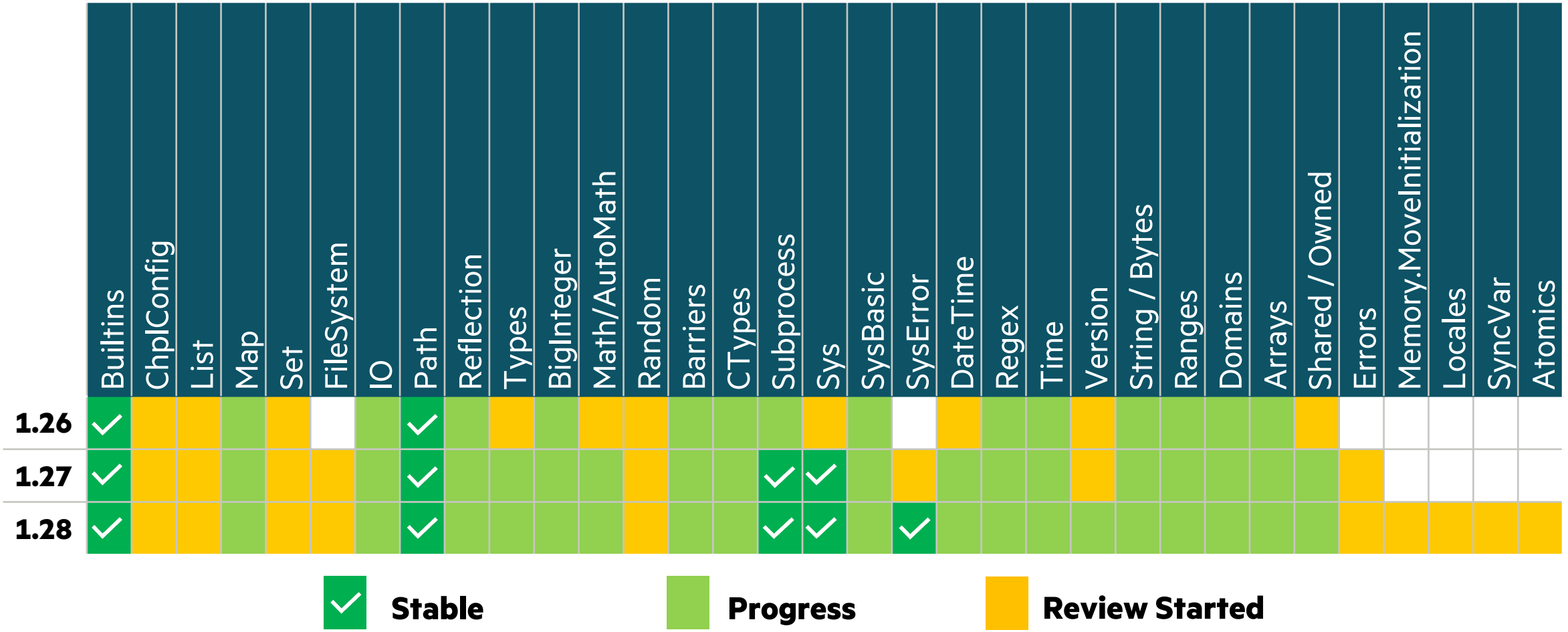
- For the past several years, we have been working toward a forthcoming Chapel 2.0 release
- Intent: stop making backward-breaking changes to core language and library features

Status as of CHIUW 2022:

- Major language-related changes were considered to have largely wound down (ha!)
- Primary remaining effort was on stabilizing the standard libraries

CHAPEL 2.0 LIBRARY STABILIZATION

Status: Visualized



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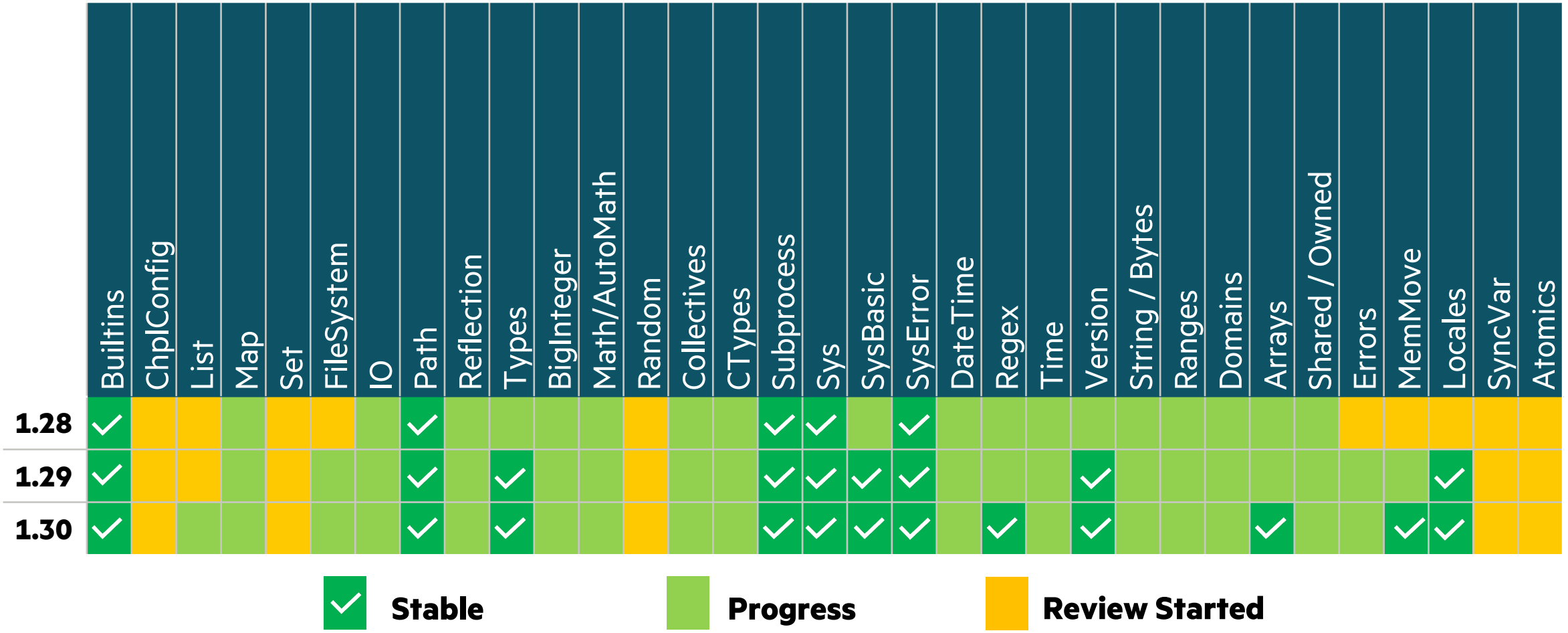
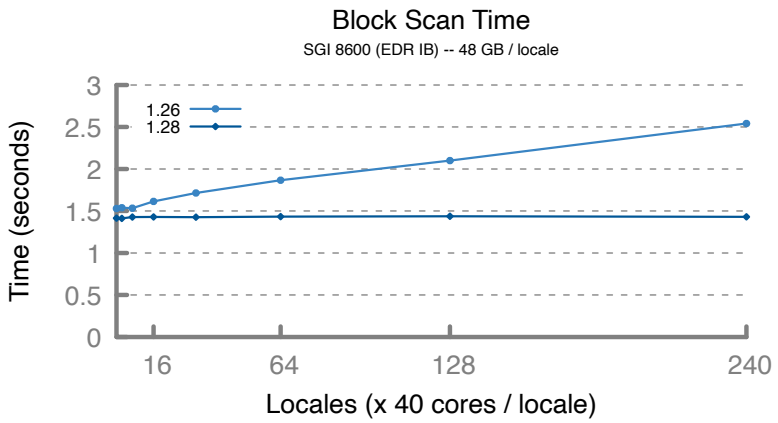


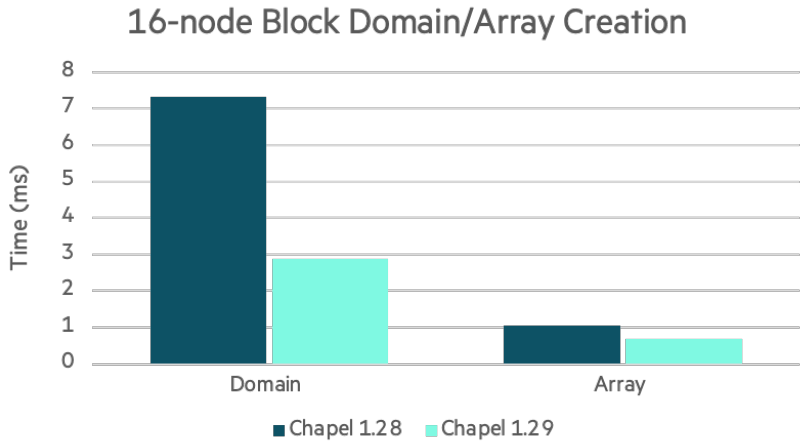
NEW LANGUAGE AND LIBRARY FEATURES

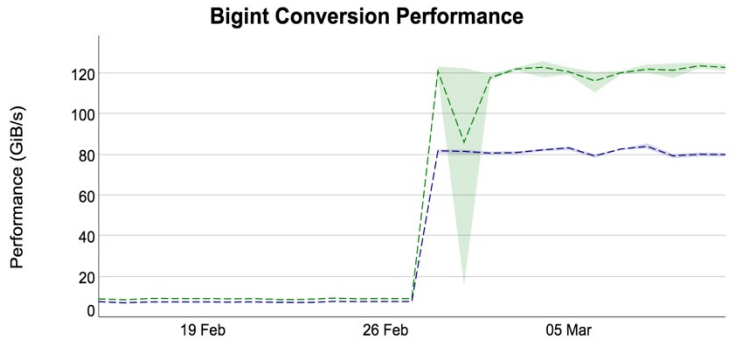
- **@attributes:** for embedding information in code outside the language
- **'Communication' module:** for single-sided puts/gets across locales
- **new first-class function syntax:** more aligned with Chapel's procedures
- **weak class pointers:** for use with 'shared'-based classes
- **throwing initializers:** for initializers whose post-field-init bodies may hit errors
- …

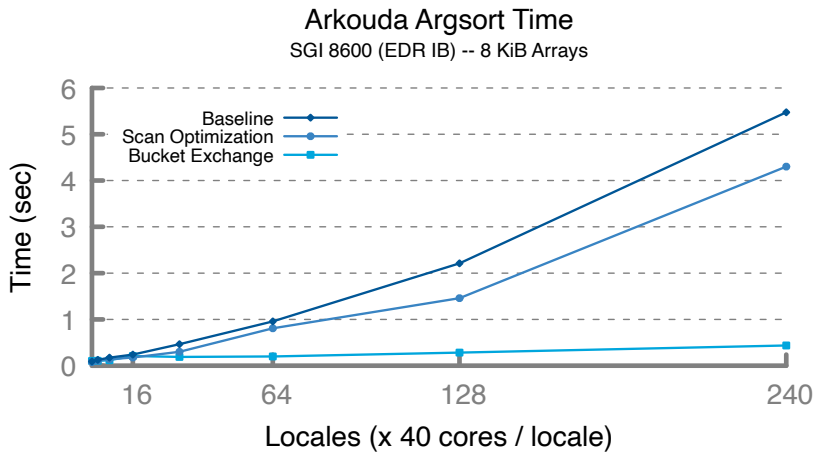
PERFORMANCE OPTIMIZATIONS

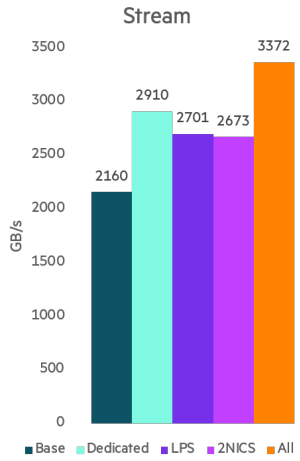
PERFORMANCE OPTIMIZATIONS

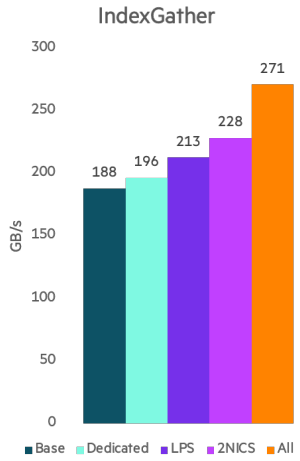


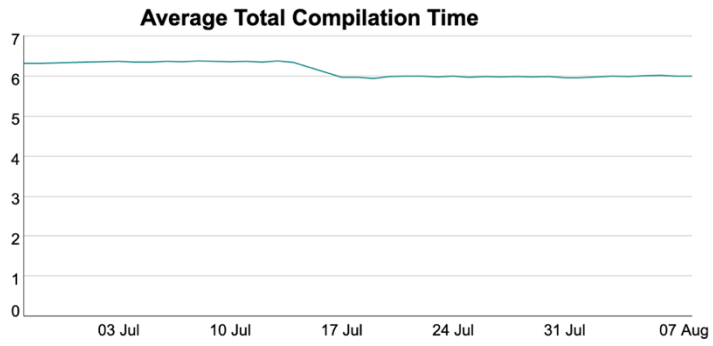








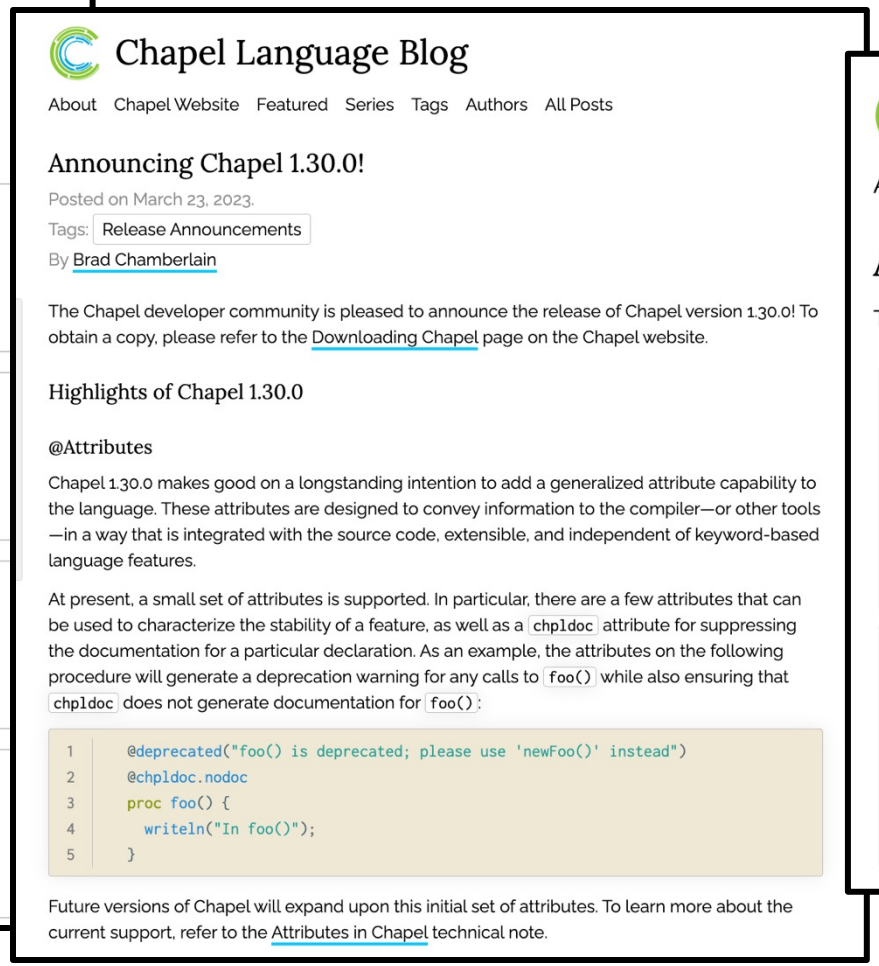


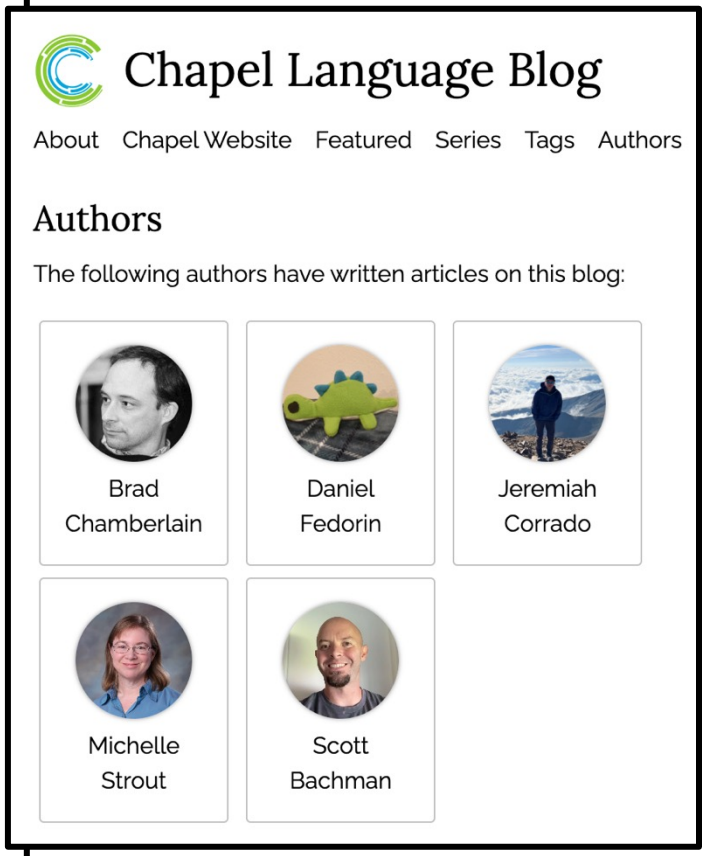


OUTREACH

CHAPEL BLOG

In December, we did a soft-launch of the Chapel Language Blog: https://chapel-lang.org/blog/





The 6th Annual Parallel Applications Workshop, Alternatives To MPI+X

Monday, November 13, 2023

Held in conjunction with SC23

Deadline: July 24, 2023
Submission Styles: Papers / Talks

WRAPPING UP

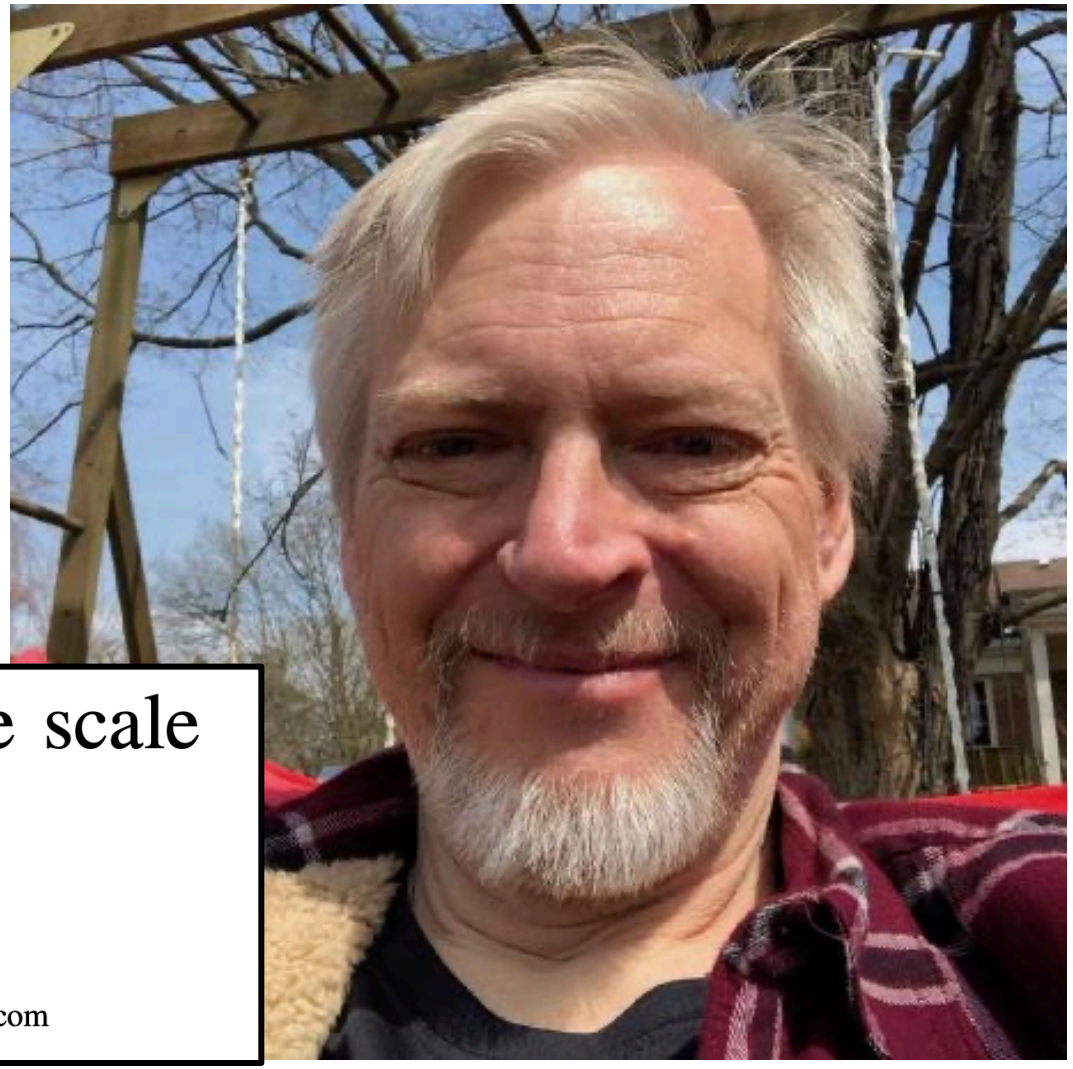
THE CHAPEL TEAM AT HPE, JUNE 2023

WHAT'S NEXT?

- **Continue with Quarterly Releases:** June, September, December, March
  - September's Chapel 1.32 will be a release candidate for Chapel 2.0
- **HPE Cray EX:** More Benchmarking and Tuning
- **Dyno:** Have it take over resolution of Calls and Types
- **GPUs:** More Features and Performance
- **Blog:** Hard-Launch
- **User Support and Outreach**
- **Performance and Feature Improvements**
- …

IN MEMORIAM

- Mike Merrill passed away on November 8th
- Mike was the chief architect and developer of Arkouda, as well as a friend to many on the Chapel project



Arkouda: NumPy-like arrays at massive scale backed by Chapel

Michael Merrill*, William Reus†, and Timothy Neumann‡
U.S. Department of Defense Washington DC, USA
Email: *mhmerrill@mac.com, †reus@post.harvard.edu, ‡timothyneumann1@gmail.com

Mike's obituary is online at: https://www.donaldsonclarksville.com/obituary/Michael-Merrill

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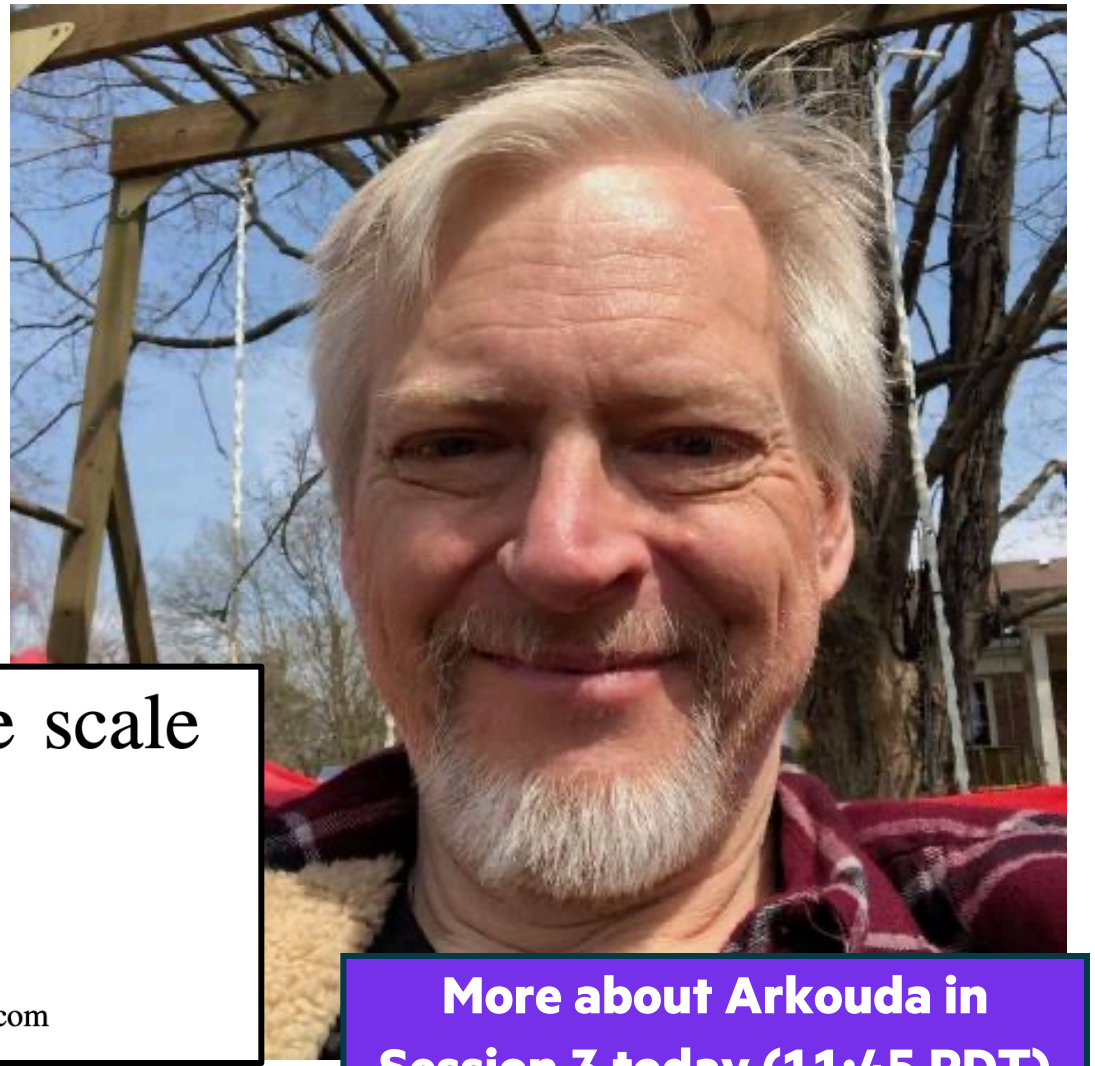

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Michael Merrill*, William Reus†, and Timothy Neumann‡
U.S. Department of Defense Washington DC, USA
Email: *mhmerrill@mac.com, †reus@post.harvard.edu, ‡timothyneumann1@gmail.com

More about Arkouda in Session 3 today (11:45 PDT)

Mike's obituary is online at: https://www.donaldsonclarksville.com/obituary/Michael-Merrill

CHAPEL RESOURCES

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

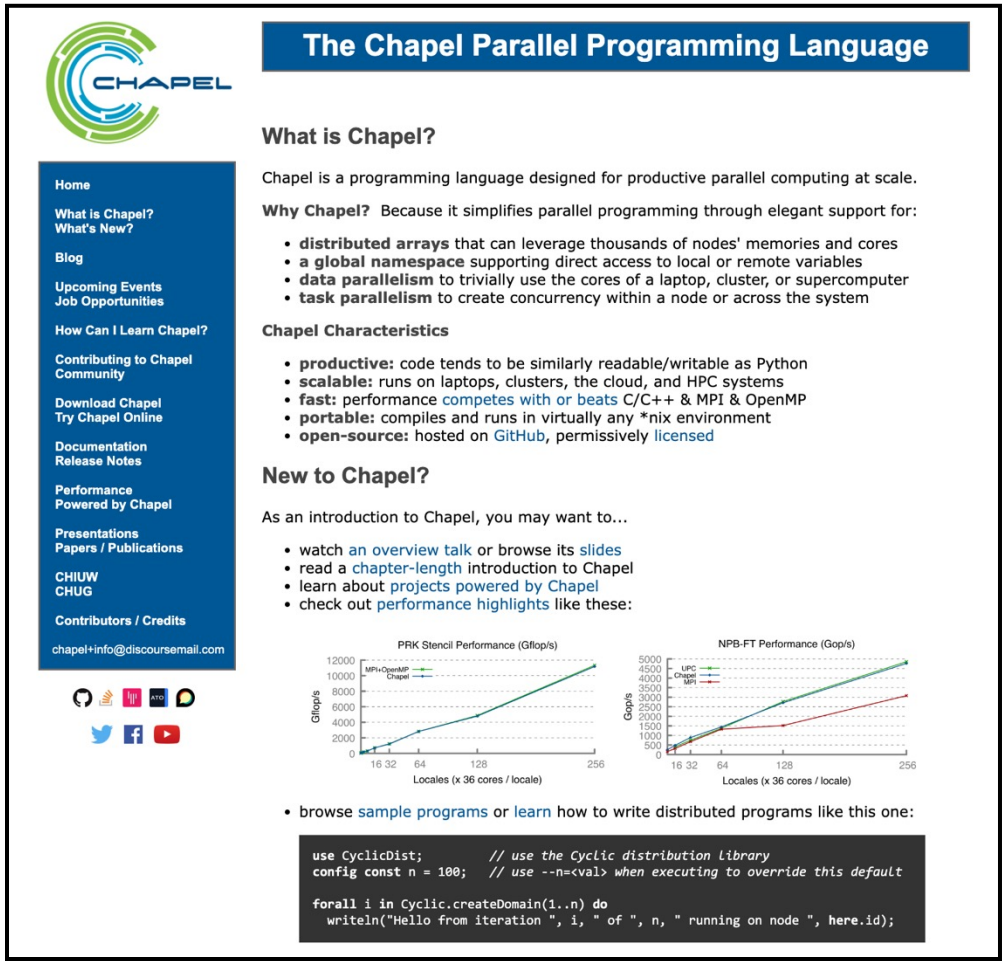
- (points to all other resources)

Social Media:

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



THANK YOU

https://chapel-lang.org
@ChapelLanguage