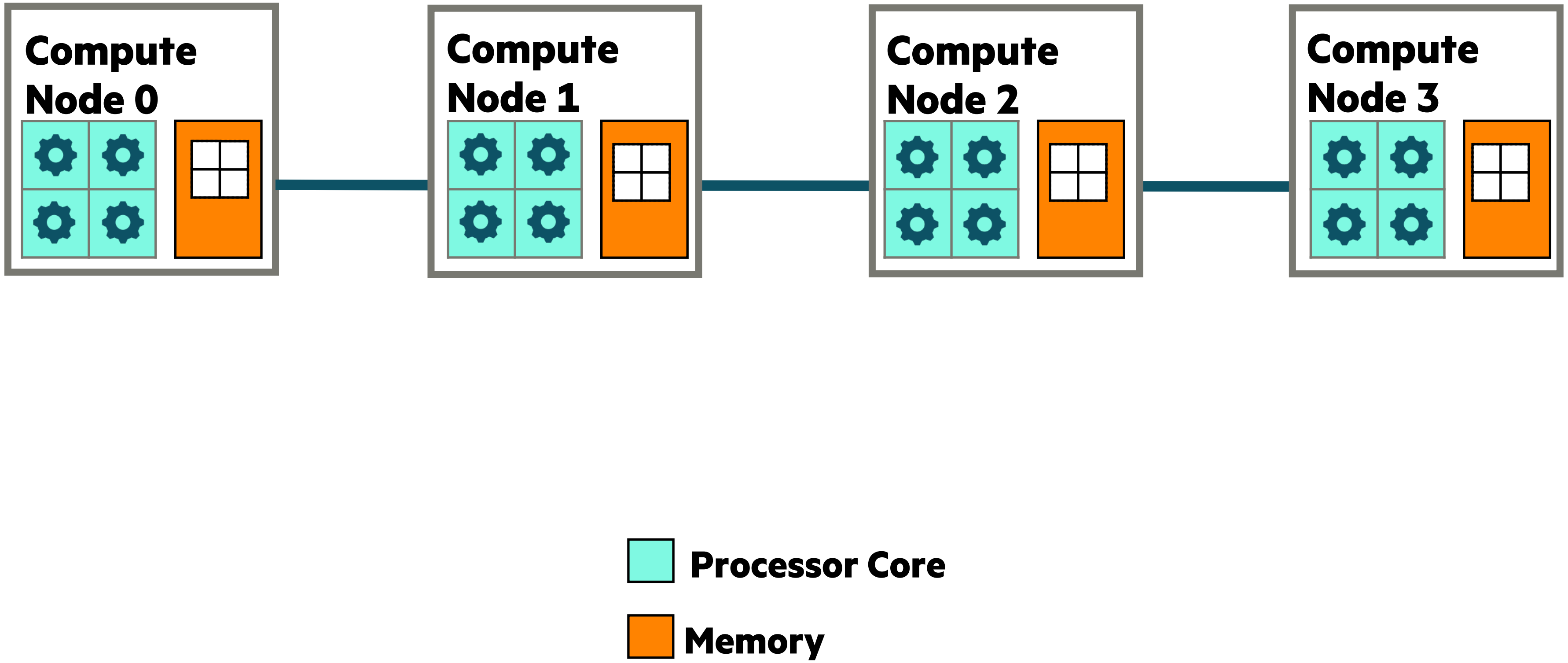
Reflections on 25 Years of Parallel Computing

Brad Chamberlain, Distinguished Technologist, Advanced Programming Team, HPE

Virginia Tech
September 4, 2026

Key Concerns for Scalable Parallel Computing

1. **parallelism:** What computational tasks should run simultaneously?
2. **locality:** Where should tasks run? Where should data be allocated?



Some Additional Background Terms

“HPC” = High-Performance Computing. For me, typically involving supercomputers (e.g., DOE exascale)

“Top500” = A semi-annual ranking of the 500 most powerful computer systems* (that participated)

* = (as measured by the Linpack benchmark)

A look back at 25 years of HPC

25 Years Ago vs. Now: Top HPC Systems in the Top500

Top 5 systems in the Top500, June 2001:

- **Cores:** 1,152–9,632
- **Rmax:** ~1,709–7,226 GFlop/s

Rank	System	Cores	Rmax (GFlop/s)	Rpeak (GFlop/s)	Power (kW)
1	ASCI White, SP Power3 375 MHz, IBM Lawrence Livermore National Laboratory United States	8,192	7,226.00	12,288.00	
2	SP Power3 375 MHz 16 way, IBM DOE/SC/LBNL/NERSC United States	2,528	2,526.00	3,792.00	
3	ASCI Red, Intel Sandia National Laboratories United States	9,632	2,379.00	3,207.00	
4	ASCI Blue-Pacific SST, IBM SP 604e, IBM Lawrence Livermore National Laboratory United States	5,808	2,144.00	3,856.50	
5	SR8000/MPP, Hitachi University of Tokyo Japan	1,152	1,709.10	2,074.00	

Top 5 systems in the Top 500, June 2026:

- **Cores:** 4,801,344–13,789,440
- **Rmax:** ~1,000–2,198 PFlop/s

Rank	System	Cores	Rmax (PFlop/s)	Rpeak (PFlop/s)	Power (kW)
1	**LineShine** - LingKun, LX2 304C 1.55GHz, LingQi, Kylin OS, Shenzhen Cloud Computing Center Co., Ltd. National Supercomputing Centre in Shenzhen (NSCS) China	13,789,440	2,198.40	2,735.82	42,220
2	**El Capitan** - HPE Cray EX255a, AMD 4th Gen EPYC 24C 1.8GHz, AMD Instinct MI300A, Slingshot-11, TOSS, HPE DOE/NNSA/LLNL United States	11,340,000	1,809.00	2,821.10	29,685
3	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE Cray OS, HPE DOE/SC/Oak Ridge National Laboratory United States	9,066,176	1,353.00	2,055.72	24,607
4	**Aurora** - HPE Cray EX - Intel Exascale Compute Blade, Xeon CPU Max 9470 52C 2.4GHz, Intel Data Center GPU Max, Slingshot-11, Intel DOE/SC/Argonne National Laboratory United States	9,264,128	1,012.00	1,980.01	38,698
5	**JUPITER Booster** - BullSequana XH3000, GH Superchip 72C 3GHz, NVIDIA GH200 Superchip, Quad-Rail NVIDIA InfiniBand NDR200, RedHat Enterprise Linux, Bull EuroHPC/FZJ Germany	4,801,344	1,000.00	1,226.28	15,794

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Cores: ~500x–12,000x
Rmax: ~138,400x–1,286,000x

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HPC HW has become far more capable...

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	Sequana XH3000, GH Superchip 200 Superchip, Quad-Rail NVIDIA , RedHat Enterprise Linux, Bull Inf Eu Ge	4,801,344	1,000.00	1,226.28	15,794

And complex!

- **commodity multicore/manycore processors**
- **multi-socket compute nodes**
- **NUMA processor/node architectures**
- **high-radix, low-diameter interconnects**
- **GPU computing**
- **multi-NIC compute nodes**

(Often in ways that hurt programmability)

25 Years Ago vs. Now: Well-established HPC Programming Notations

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Well-established HPC notations, June 2001:

- **Languages:** Fortran, C, C++, UPC
- **Inter-node:** MPI, PVM, SHMEM
- **Intra-node:** Pthreads, OpenMP
- **Scripting:** Perl, sh/csh/tcsh, Tcl/TK

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HPC SW notations have largely stayed the same, modulo GPU computing and scripting

Well-established HPC notations, June 2026:

Notably, HPC has failed to broadly adopt any new programming languages…

- **Languages:** Fortran, C, C++
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seemingly, each new flavor of hardware parallelism brings a brand new software notation

Why hasn’t HPC broadly adopted any new languages?

Is it because language design is dead?

"Programming language design ceased to be relevant in the 1980s."

—Anonymous reviewer, circa 1995 (paraphrased, from memory)

Seems unlikely…

- Consider some of the currently relevant languages that emerged or rose to prominence during those ~25 years:
  - **Python** (~1991; v2.0 ~2000)
  - **C#** (~2000)
  - **Go** (~2009)
  - **Rust** (~2012)
  - **Julia** (~2012)
  - **Swift** (~2014)

Such languages have become favorite day-to-day languages of many users across multiple disciplines

That said, they are not particularly HPC-ready—primarily due to lack of locality control

Consider the “hooks” for these languages

Why were they developed? Why did they take hold?

Language	Productivity	Safety	Portability	Performance
Python	✅	✅		
C#		✅	✅	
Go	✅			✅
Rust		✅		✅
Julia	✅			✅
Swift	✅	✅		✅

Note: lack of a ✅ doesn’t mean a language doesn’t have that quality; just that I don’t consider it a major factor in its design/adoption.

These four themes are extremely valuable in HPC programming as well

Is it because HPC doesn't need new languages?

Libraries, directives, and extensions have obviously gotten us quite far

- Virtually all notable HPC computations from the past 30 years have used them

Yet, using C++ with MPI + OpenMP and/or CUDA leaves a lot to be desired in terms of…

…productivity

…safety

…automated optimizations

We're living in a state that's similar to Fortran's introduction as an alternative to assembly

- moving data around the memory hierarchy manually
- skeptical about higher-level approaches; hesitant to give up control and performance
- undervaluing the benefits of readability, maintainability, safety, compiler checks and optimizations, …

Programming languages offer unique advantages over libraries and extensions

Is it because parallel computing is niche?

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Availability of parallelism, June 2001

- HPC systems at national labs, universities, industry

Parallelism has expanded beyond HPC, dramatically!

Availability of parallelism, June 2026:

- HPC systems at national labs, universities, industry
- laptops / desktops with multicore CPUs and GPUS
- single-board computers (SBCs)
- cloud computing, AI data centers, …

Is it for lack of trying?

Definitely not! Here are some notable attempts from the past 25 years:

- **Mid-to-late 90's Classics:**
  - High Performance Fortran (HPF)
  - NESL
  - Single-Assignment C (SAC)
  - ZPL
- **PGAS founding members:**
  - Coarray Fortran (CAF)
  - Unified Parallel C (UPC)
  - Titanium
- **C-based approaches:**
  - Cilk
  - SAC: Single-Assignment C
- **HPCS-era languages:**
  - Chapel
  - Fortress
  - X10
  - Coarray Fortran 2.0
- **Post-HPCS:**
  - XcalableMP
  - Regent
- **Embedded pseudo-languages**
  - Charm++, Coarray C++, COMPSs, Global Arrays, HPX, Lamellar, Legion, UPC++, …
- **And many more…**

Not all of these attempts have been worthy of broad adoption…

But also, past failures at achieving broad adoption don't mean we should stop trying!

What is Chapel?

Chapel: A modern parallel programming language

- Portable & scalable
- Open-source & collaborative
  - an HPSF / Linux Foundation project

Goals:

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

Origin Story: DARPA High Productivity Computing Systems program

- conceived of in Dec 2002 (~24 years ago)
- design gained traction in 2006
- first public release in 2008

Reflections on 25 Years of Parallel Computing:
Hardware transformations, programming incrementalism, and the tenacity of Chapel

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Chapel pre-dates all of the HW technology changes mentioned earlier.

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Yet it supports them using the same features for parallelism and locality that we designed 20+ years ago

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key: express parallelism and locality independently of hardware mechanisms

25 Years Ago vs. Now: How does Chapel fit into the picture?

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Chapel replaces the need to mix multiple notations:
Use a single language for parallelism at all levels,
targeting parallel systems of all types and scales

key: express parallelism and locality independently of hardware mechanisms

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Unified
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CHAPEL

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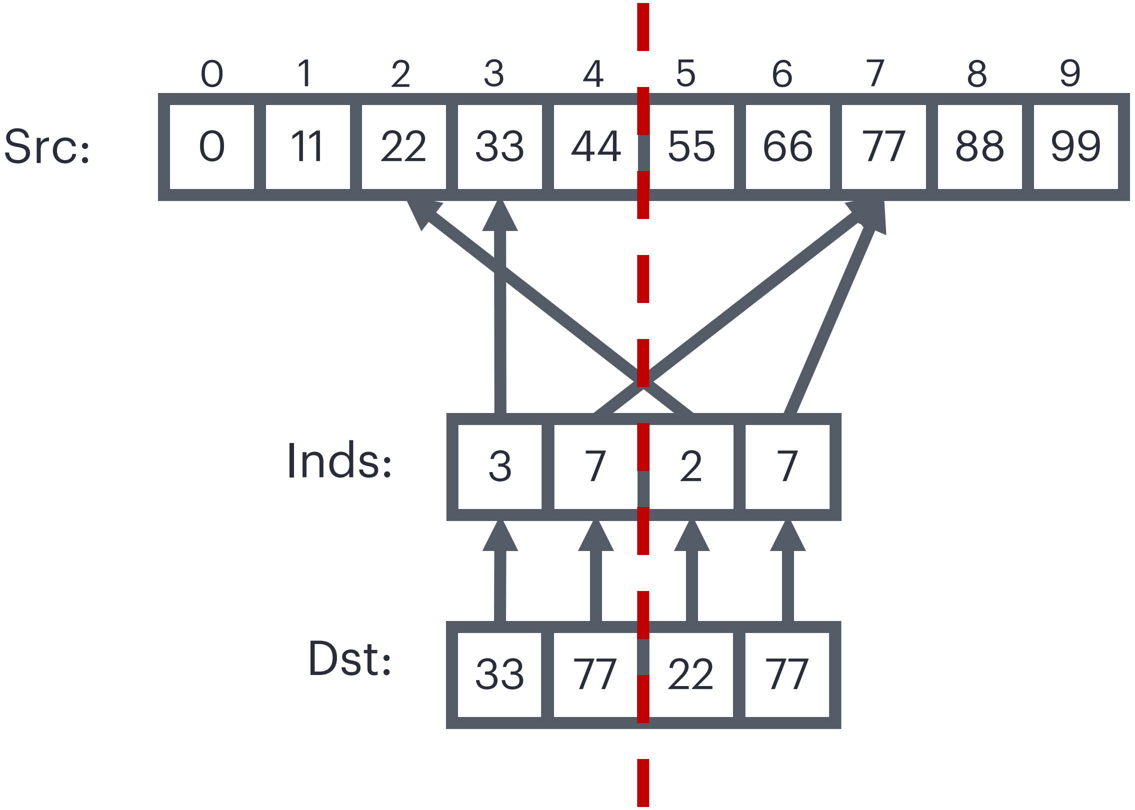
High-Level Chapel By Example: Bale Index Gather

Bale Index Gather (IG): In Pictures



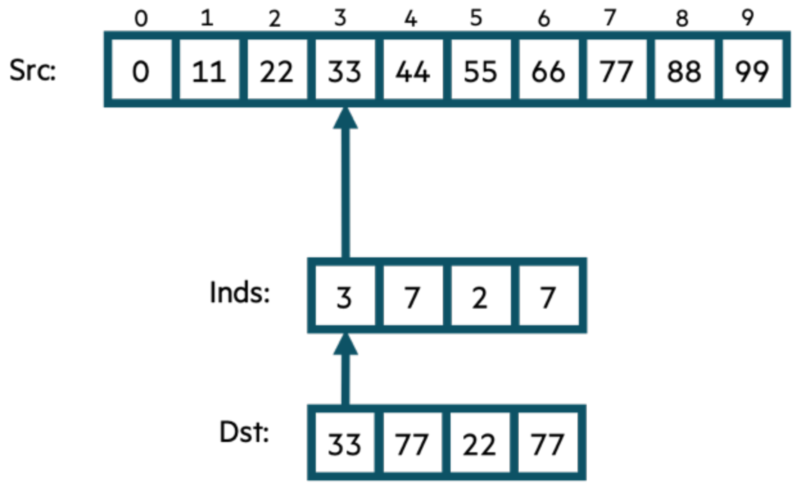
Bale IG in Chapel: Declarations and Main Loop (Sequential Version)

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
for (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$
```



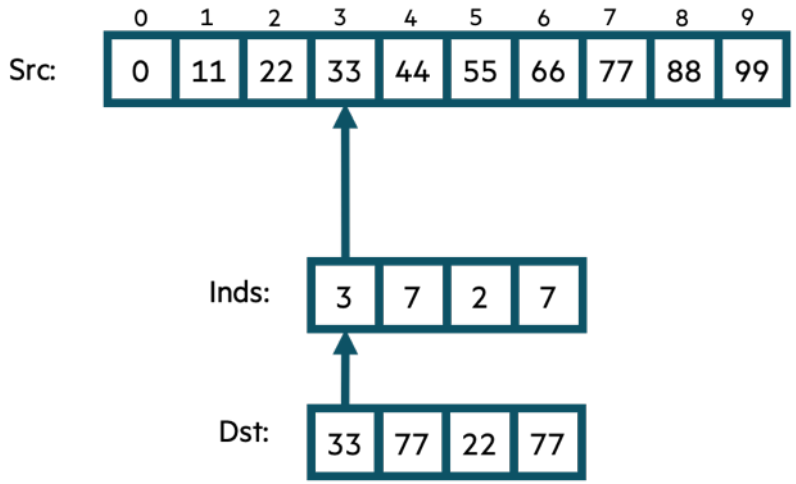
Bale IG in Chapel: Compiling

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
for (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$
```



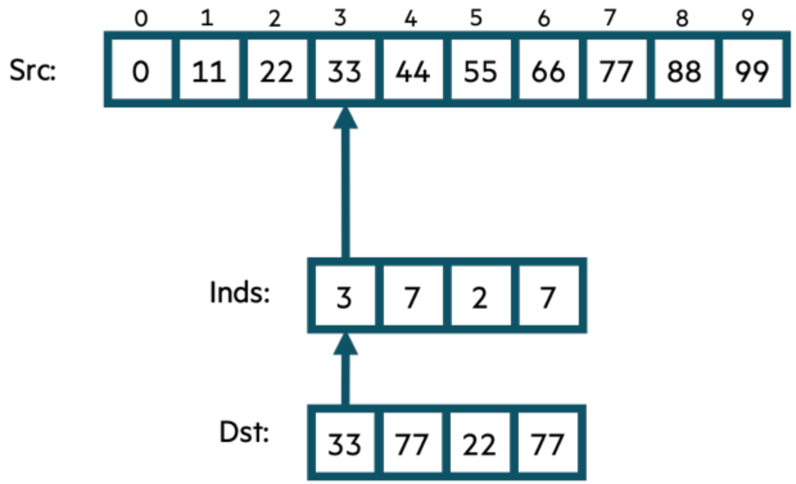
Bale IG in Chapel: Executing

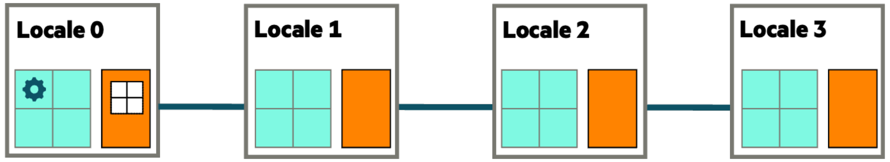
```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
for (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```





Bale IG in Chapel: Parallel, Zippered Version (Multicore)

```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
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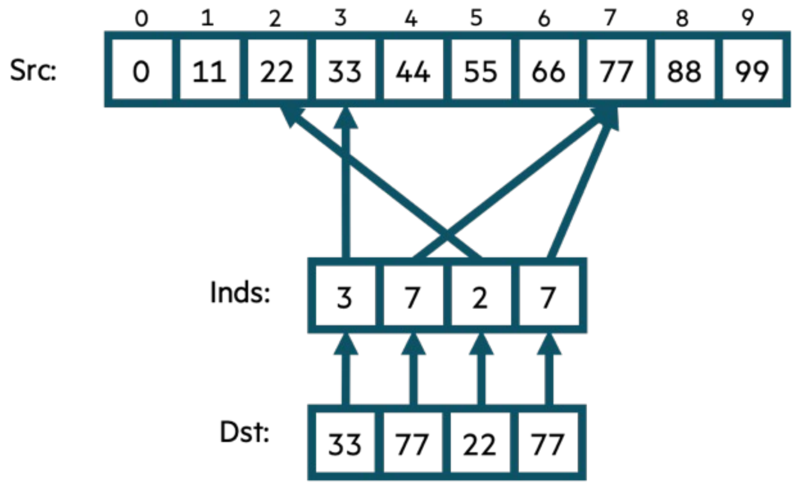
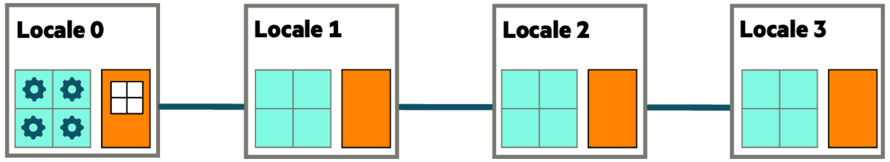
$ ./bale-ig -nl 4
$
```





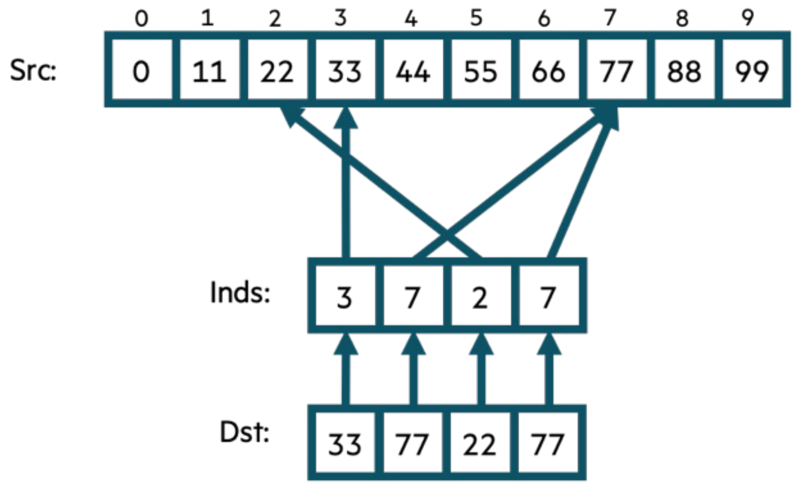
Bale IG in Chapel: Parallel, Zippered Version with Named Domains (Multicore)

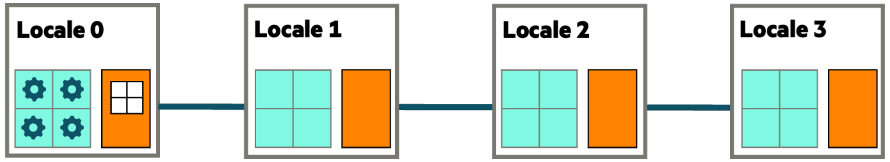
```
config const n = 10,
             m = 4;

const SrcInds = {0..<n},
      DstInds = {0..<m};

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```





Bale IG in Chapel: Distributed Parallel Version

```
use BlockDist;

config const n = 10,
             m = 4;

const SrcInds = blockDist.createDomain(0..<n),
      DstInds = blockDist.createDomain(0..<m);

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
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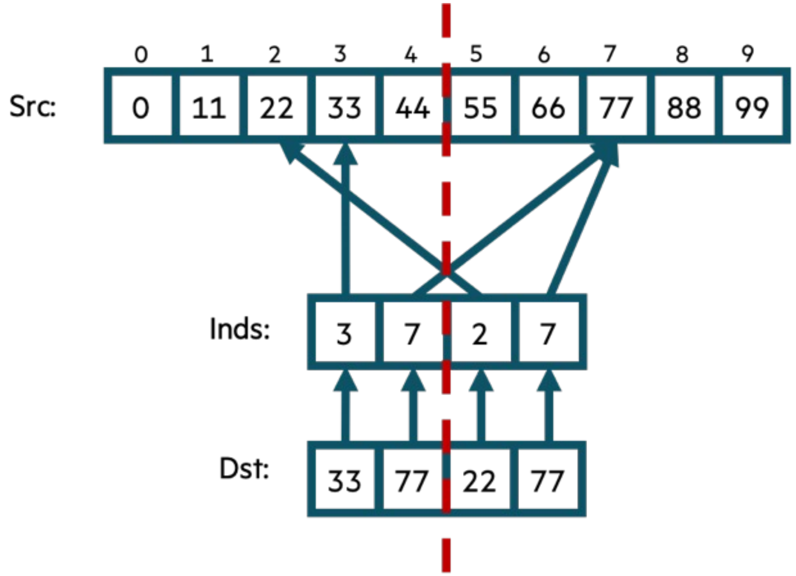
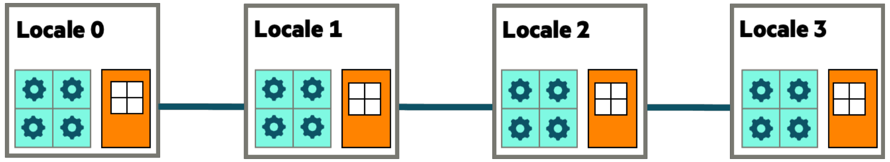




Bale IG in Chapel: Distributed Parallel Version on HPE Cray EX

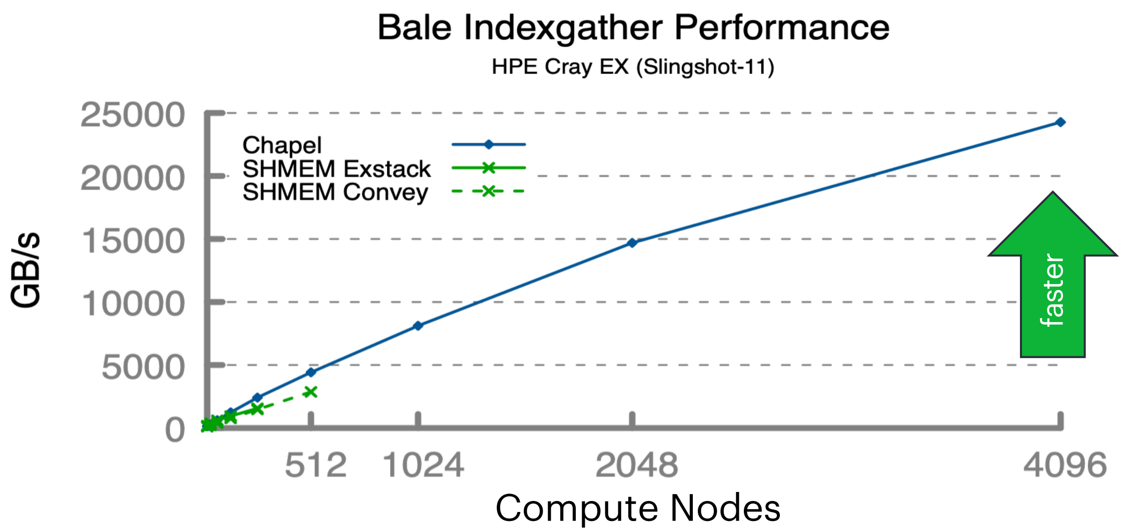
```
use BlockDist;

config const n = 10,
             m = 4;

const SrcInds = blockDist.createDomain(0..<n),
      DstInds = blockDist.createDomain(0..<m);

var Src: [SrcInds] int,
    Inds, Dst: [DstInds] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl --fast --auto-aggregation
$ ./bale-ig -nl 4096 --n=… --m=…
$
```



Bale IG in Chapel vs. SHMEM on HPE Cray EX

Chapel

```
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

SHMEM (Exstack version)

```
i=0;
while( exstack_proceed(ex, (i==l_num_req)) ) {
  i0 = i;
  while(i < l_num_req) {
    l_indx = pckindx[i] >> 16;
    pe   = pckindx[i] & 0xffff;
    if(!exstack_push(ex, &l_indx, pe))
      break;
    i++;
  }

  exstack_exchange(ex);

  while(exstack_pop(ex, &idx , &fromth)) {
    idx   = ltable[idx];
    exstack_push(ex, &idx, fromth);
  }
  lgp_barrier();
  exstack_exchange(ex);

  for(j=i0; j<i; j++) {
    fromth = pckindx[j] & 0xffff;
    exstack_pop_thread(ex, &idx, (uint64_t)fromth);
    tgt[j] = idx;
  }
  lgp_barrier();
}
```

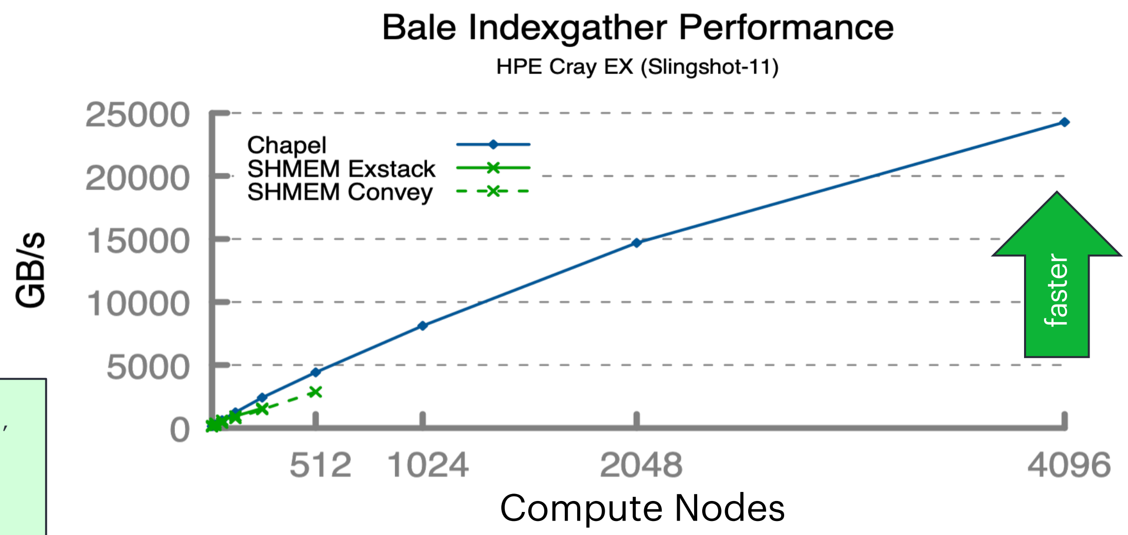
SHMEM (Conveyors version)

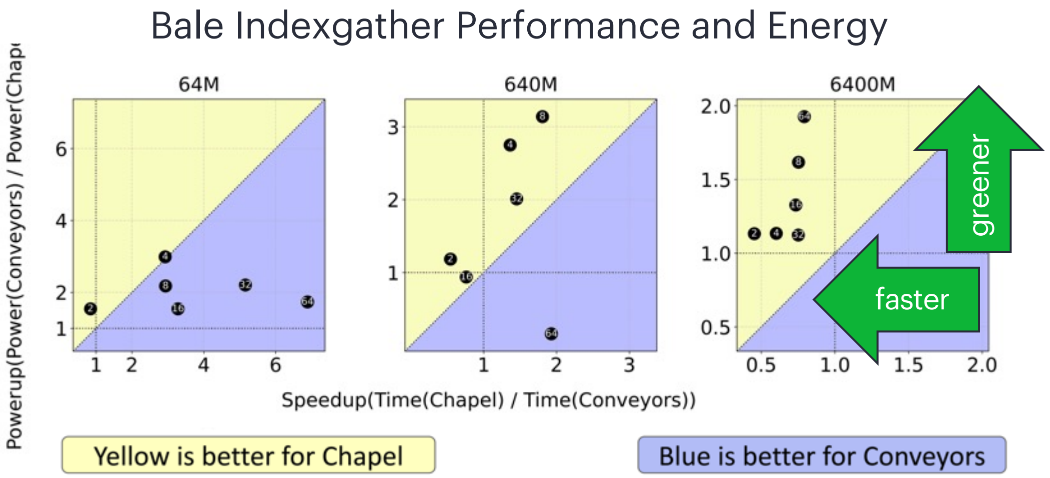
```
i = 0;
while (more = convey_advance(requests, (i == l_num_req)),
       more | convey_advance(replies, !more)) {

  for (; i < l_num_req; i++) {
    pkg.idx = i;
    pkg.val = pckindx[i] >> 16;
    pe = pckindx[i] & 0xffff;
    if (! convey_push(requests, &pkg, pe))
      break;
  }

  while (convey_pull(requests, ptr, &from) == convey_OK) {
    pkg.idx = ptr->idx;
    pkg.val = ltable[ptr->val];
    if (! convey_push(replies, &pkg, from)) {
      convey_unpull(requests);
      break;
    }
  }

  while (convey_pull(replies, ptr, NULL) == convey_OK)
    tgt[ptr->idx] = ptr->val;
}
```





[performance and energy results from *Heading Towards Energy Savings or Just Performance: Case-Study on Message Aggregation-Based Runtimes*, Shubhendra Pal Singhal et al., CUG 2026, April 28, 2026]

Applications of Chapel

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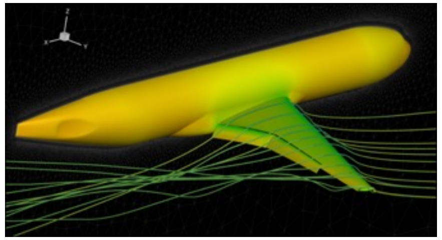
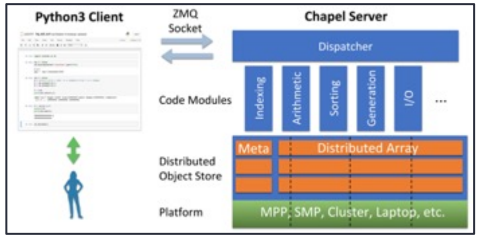
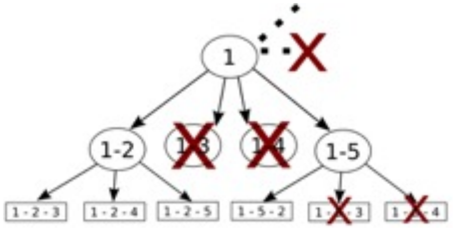


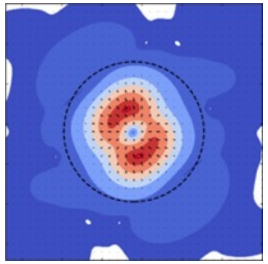
CHAMPS: 3D Unstructured CFD
Laurendeau, Bourgault-Côté, Parenteau, Plante, et al.
École Polytechnique Montréal



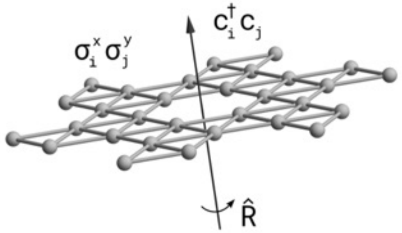
Arkouda: Interactive Data Science at Massive Scale
Mike Merrill, Bill Reus, et al.
U.S. DoD



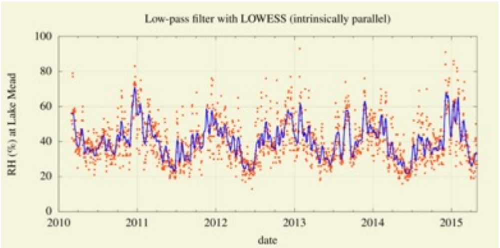
ChOp: Chapel-based Optimization
T. Carneiro, G. Helbecque, N. Melab, et al.
INRIA, IMEC, et al.



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

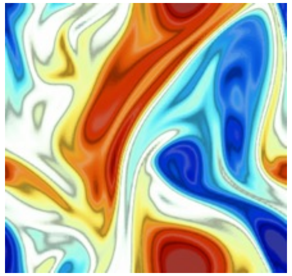


Lattice-Symmetries: a Quantum Many-Body Toolbox
Tom Westerhout
Radboud University

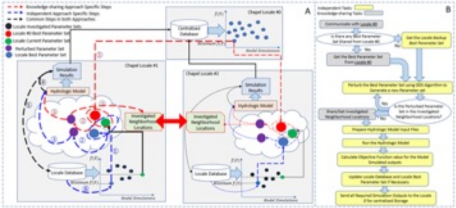


Desk dot chpl: Utilities for Environmental Eng.
Nelson Luis Dias
The Federal University of Paraná, Brazil

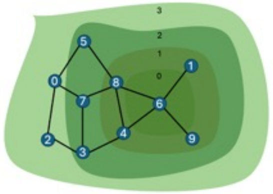
RapidQ: Mapping Coral Biodiversity
Rebecca Green, Helen Fox, Scott Bachman, et al.
The Coral Reef Alliance



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

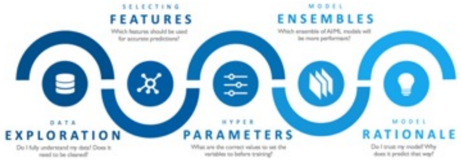


Chapel-based Hydrological Model Calibration
Marjan Asgari et al.
University of Guelph



Arachne Graph Analytics
Bader, Du, Rodriguez, et al.
New Jersey Institute of Technology

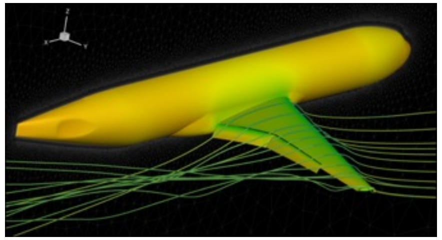
Modeling Ocean Carbon Dioxide Removal
Scott Bachman Brandon Neth, et al.
[C]Worthy



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

[images provided by their respective teams and used with permission]

Productivity Across Diverse Application Scales (code and system size)



Computation: Aircraft simulation / CFD
Code size: 100,000+ lines
Systems: Desktops, HPC systems

7 Questions for Éric Laurendeau: Computing Aircraft Aerodynamics in Chapel

Posted on September 17, 2024.

Tags: Computational Fluid Dynamics | User Experiences | Interviews

By: Engin Kayraklioglu, Brad Chamberlain

"Chapel worked as intended: the code maintenance is very much reduced, and its readability is astonishing. This enables undergraduate students to contribute, something almost impossible to think of when using very complex software."

Computation: Coral reef image analysis
Code size: ~300 lines
Systems: Desktops, HPC systems w/ GPUs

7 Questions for Scott Bachman: Analyzing Coral Reefs with Chapel

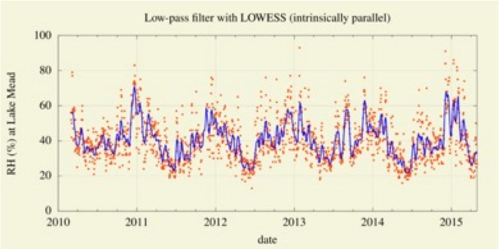
Posted on October 1, 2024.

Tags: Earth Sciences | Image Analysis | GPU Programming | User Experiences | Interviews

By: Brad Chamberlain, Engin Kayraklioglu

In this second installment of our Seven Questions for Chapel Users series, we're looking at a recent success story in which Scott Bachman used Chapel to unlock new scales of biodiversity analysis in coral reefs to study ocean health using satellite image processing. This is work that

"With the coral reef program, I was able to speed it up by a factor of 10,000. Some of that was algorithmic, but Chapel had the features that allowed me to do it."



Computation: Atmospheric data analysis
Code size: 5000+ lines
Systems: Desktops, sometimes w/ GPUs

7 Questions for Nelson Luís Dias: Atmospheric Turbulence in Chapel

Posted on October 15, 2024.

Tags: User Experiences | Interviews | Data Analysis | Computational Fluid Dynamics

By: Engin Kayraklioglu, Brad Chamberlain

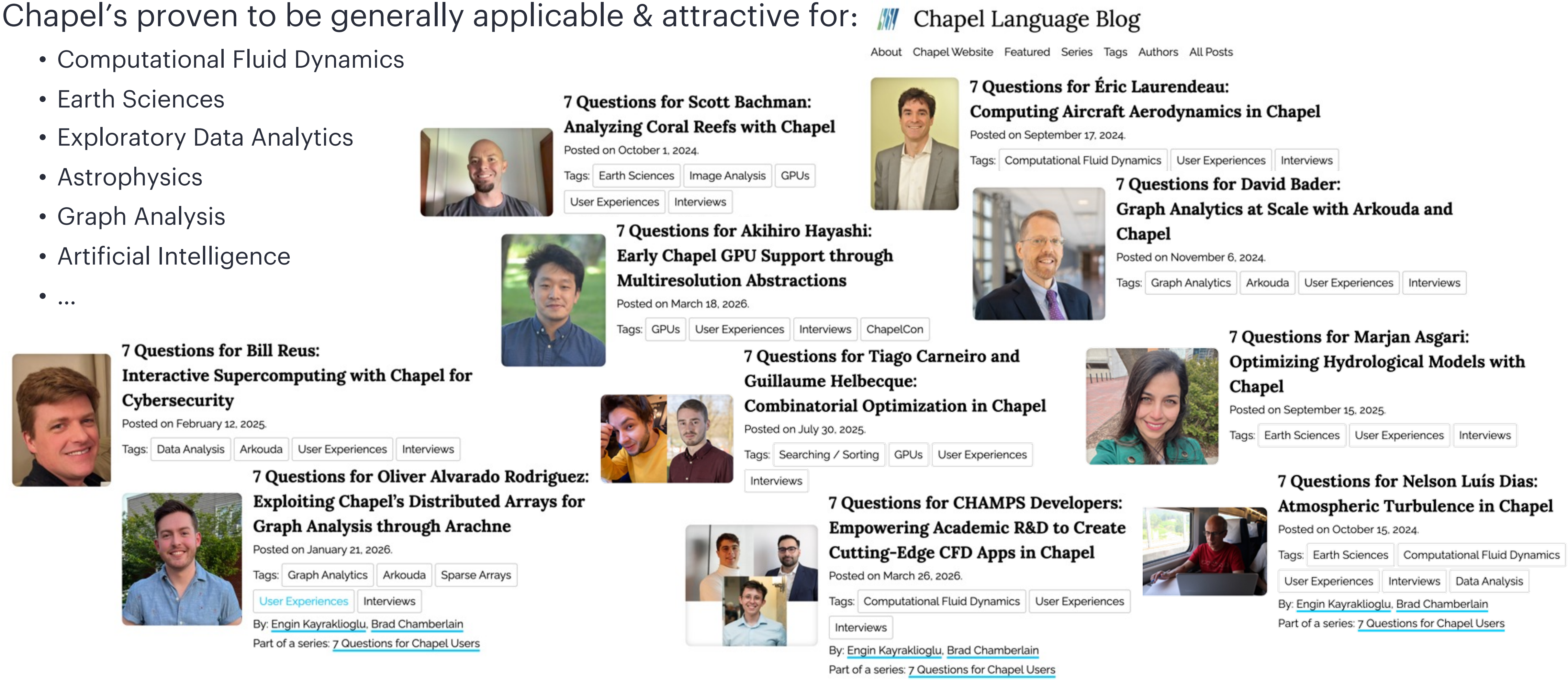
In this edition of our Seven Questions for Chapel Users series, we turn to Dr. Nelson Luís Dias from Brazil who is using Chapel to analyze data generated by the Amazon Tall Tower Observatory (ATTO), a project dedicated to long-term, 24/7 monitoring of greenhouse gas fluctuations. Read on

"Chapel allows me to use the available CPU and GPU power efficiently without low-level programming of data synchronization, managing threads, etc."

For more, see “7 Questions for Chapel Users” Blog Interviews

Chapel’s proven to be generally applicable & attractive for:

- Computational Fluid Dynamics
- Earth Sciences
- Exploratory Data Analytics
- Astrophysics
- Graph Analysis
- Artificial Intelligence
- …



https://chapel-lang.org/blog/series/7-questions-for-chapel-users/

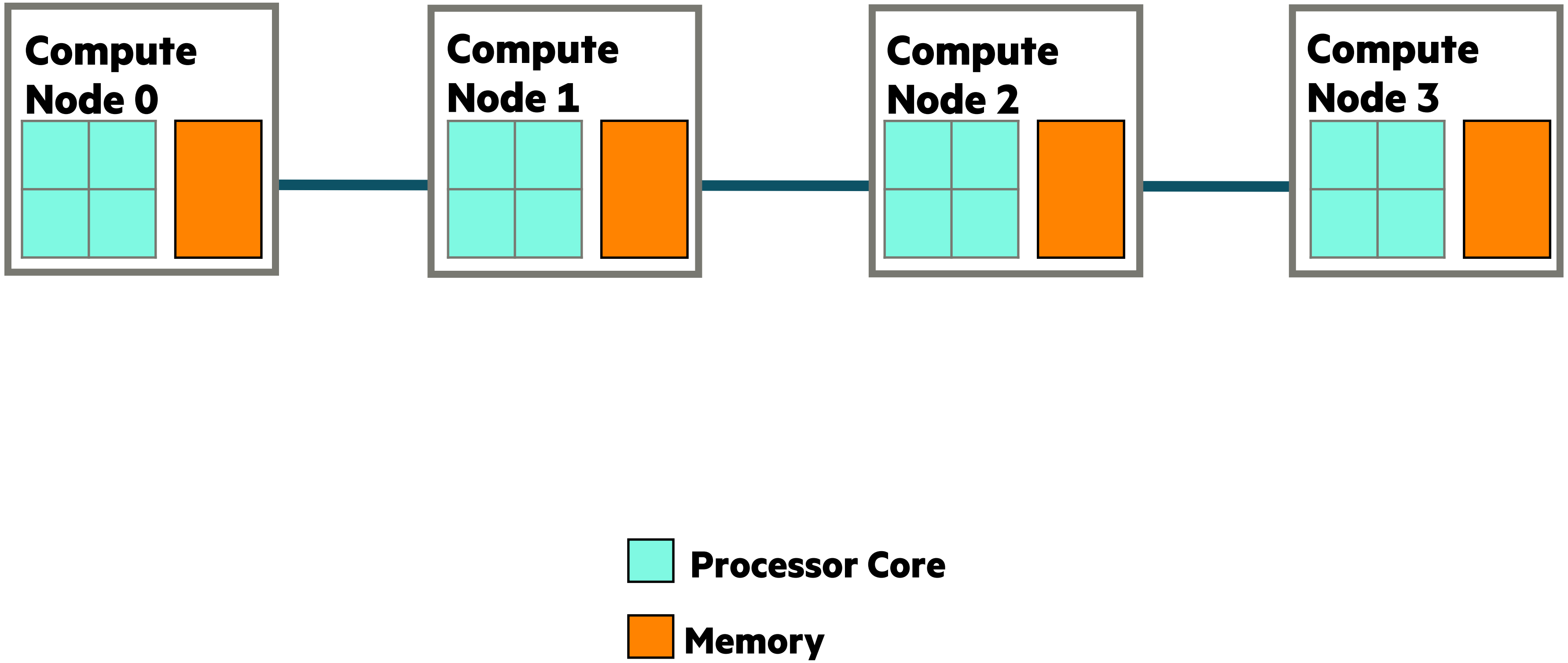
“Low-level” Chapel Features and GPU support

Locales in Chapel

In Chapel, a *locale* refers to a compute resource with…

- processors, so it can run tasks
- memory, so it can store variables

For now, think of each compute node as being a locale



Locales in Chapel

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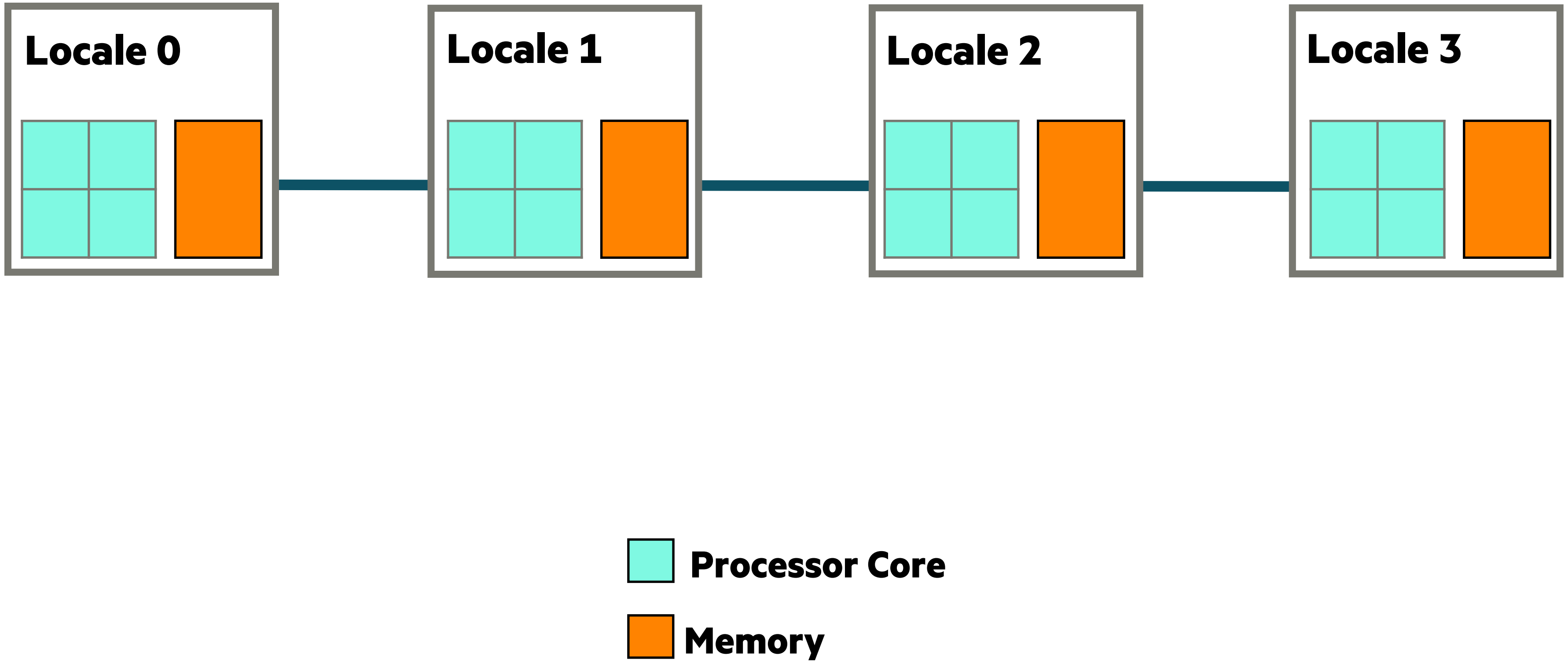


Basic Features for Locality

```
writeln("Hello from locale ", here.id);

var A: [1..2, 1..2] real;

for loc in Locales {
  on loc {
    var B = A;
  }
}
```

All Chapel programs begin running as a single task on locale 0

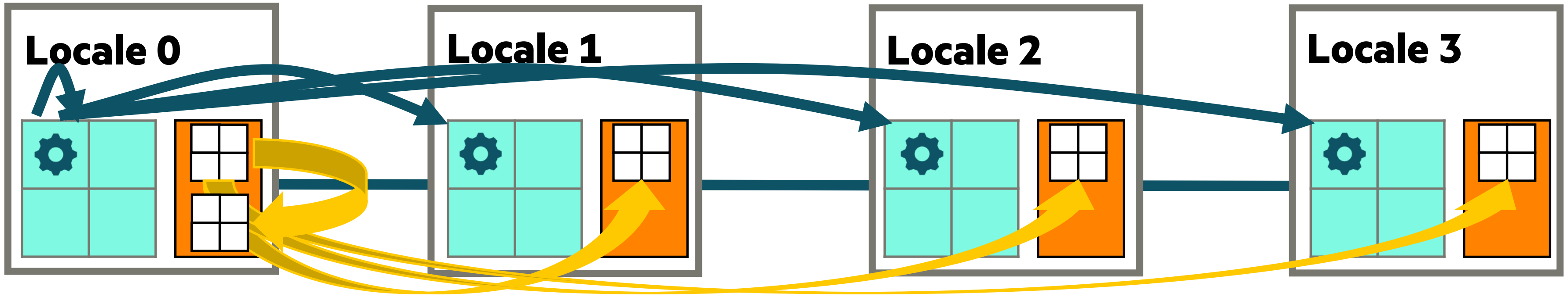
Variables are stored using the memory local to the current task

This loop will iterate sequentially over the program's locales

on-clauses move tasks to target locales

remote variables can be accessed directly

This is a distributed, yet sequential, computation



Mixing Locality with Task Parallelism

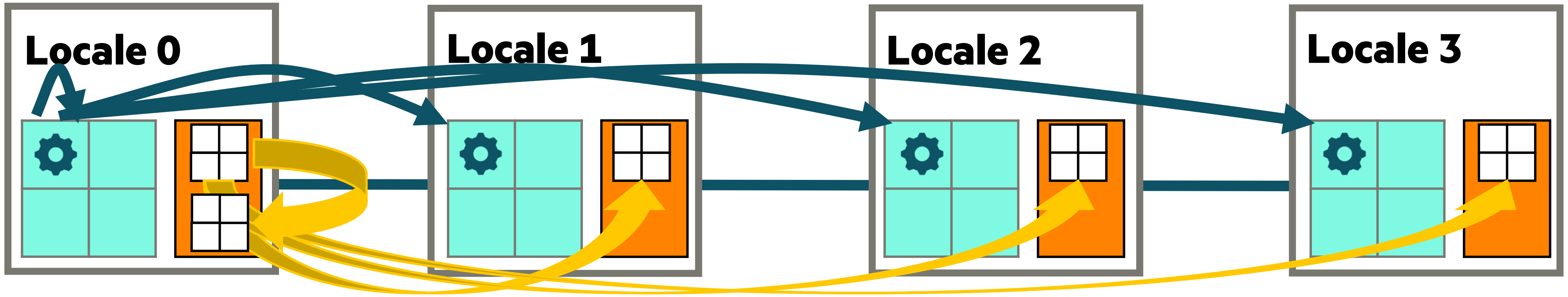
```
writeln("Hello from locale ", here.id);

var A: [1..2, 1..2] real;

coforall loc in Locales {
  on loc {
    var B = A;
  }
}
```

The coforall loop creates
a parallel task per iteration
(in this case, a task per locale)

This is a distributed parallel computation



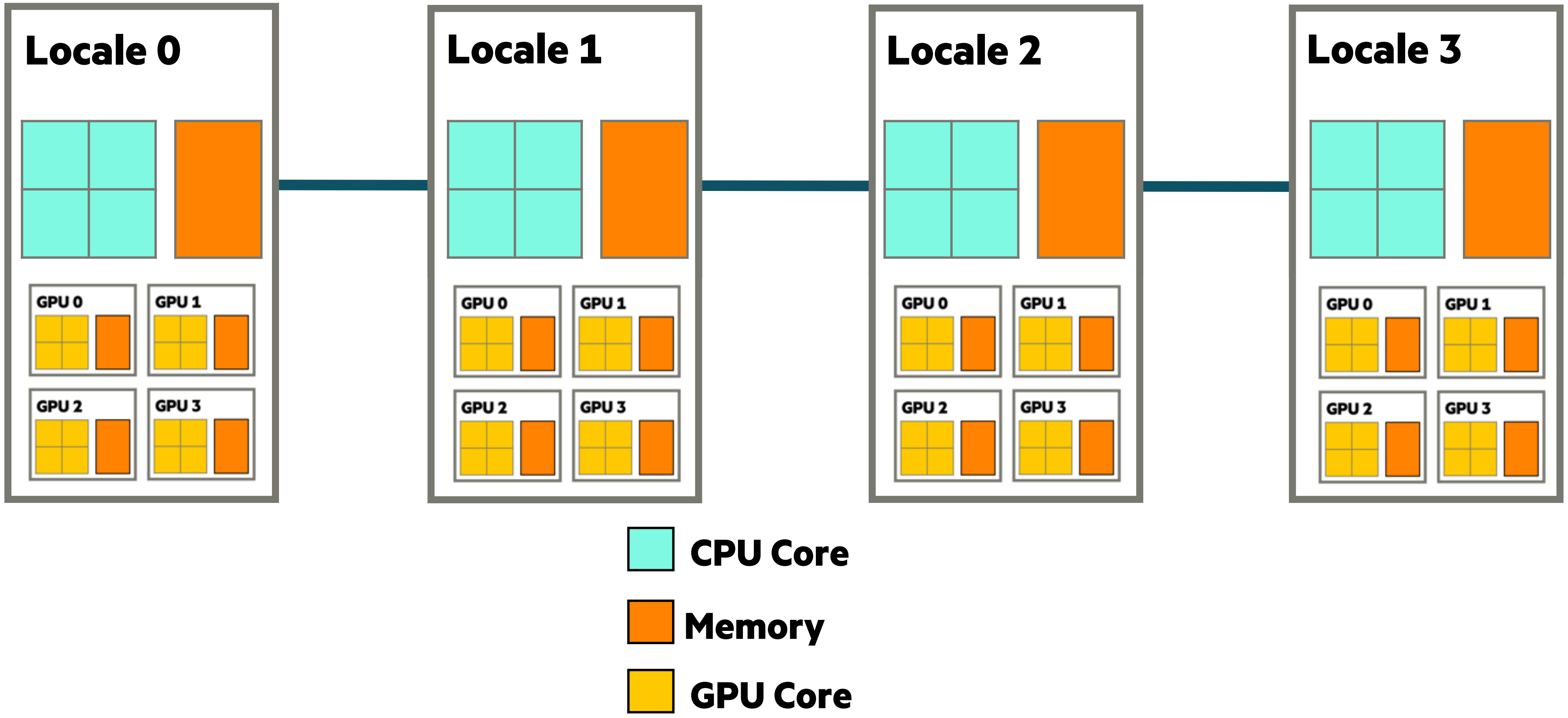
Chapel with GPUs

In Chapel, we represent GPUs as *sub-locales*

- Each top-level locale may have an array of locales called ‘gpus’
- We can then target them using Chapel’s traditional features for parallelism + locality

`on here.gpus[0] { … }`

`coforall gpu in here.gpus do on gpu { … }`



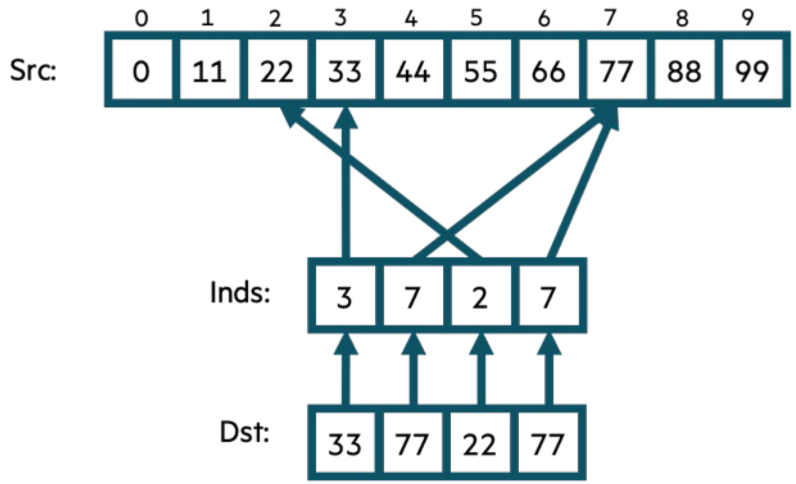
Bale IG in Chapel: Parallel, Zippered Version (Multicore)

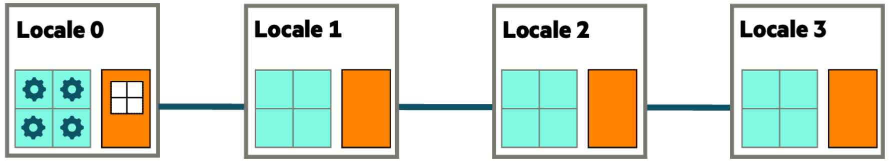
```
config const n = 10,
             m = 4;



var Src: [0..<n] int,
    Inds, Dst: [0..<m] int;
…
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```





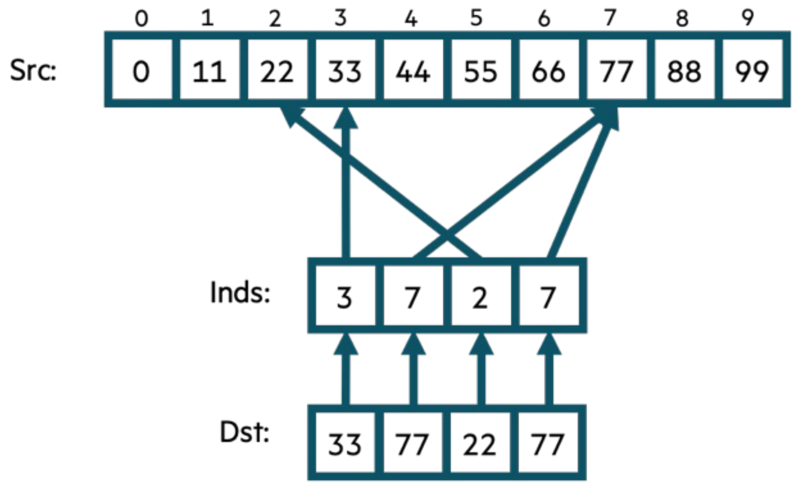
Bale IG in Chapel: Parallel, Zippered Version (single GPU)

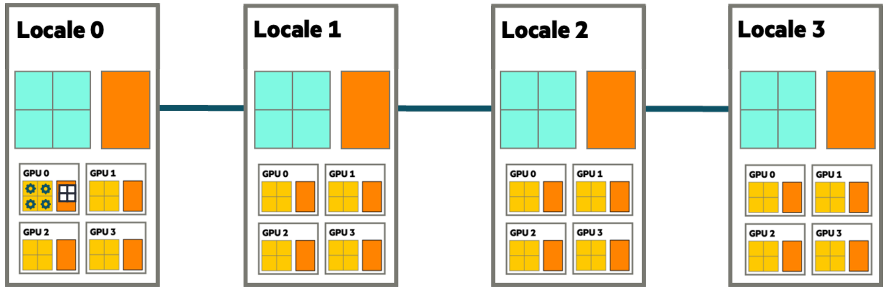
```
  config const n = 10,
               m = 4;



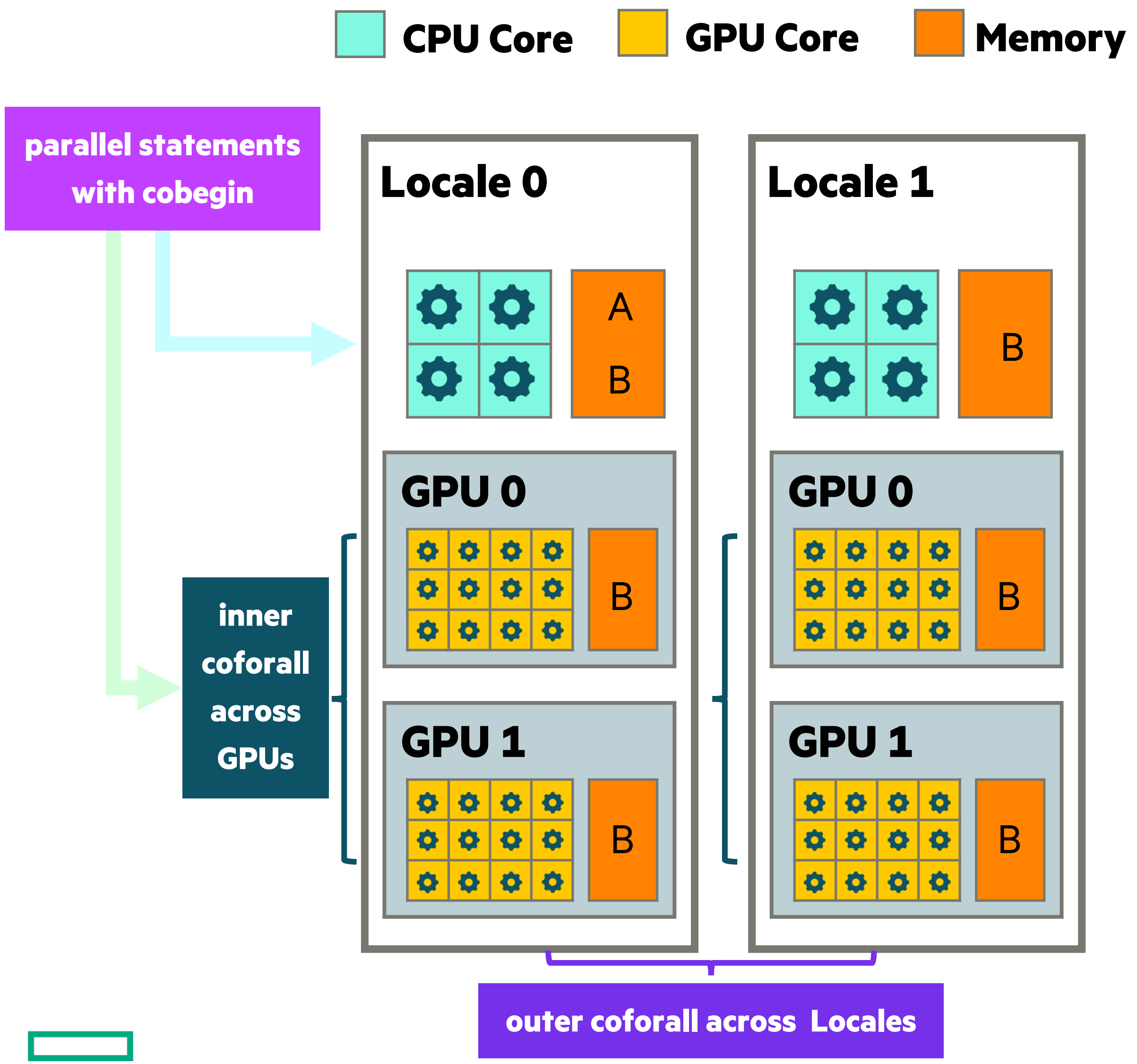

on here.gpus[0] {
  var Src: [0..<n] int,
      Inds, Dst: [0..<m] int;
  …
  forall (d, i) in zip(Dst, Inds) do
    d = Src[i];
}
```

```
$ chpl bale-ig.chpl
$ ./bale-ig -nl 4
$
```





Targeting CPUs and GPUs using Parallelism and Locality




```
var A: [1..n, 1..n] real;
coforall l in Locales do on l {
  cobegin {
   {
     var B: [1..n, 1..n] real;
     B = 2;
     A = B;
   }
   coforall g in here.gpus do on g {
     var B: [1..n, 1..n] real;
     B = 2;
     A = B;
   }
  }
}
writeln(A);
```

Wrap-up & Closing Thoughts

Where Does Chapel Run?

In the Browser:
- Attempt This Online (ATO)
- GitHub Codespaces

Laptops/Desktops:
- Linux/UNIX
- Mac OS X
- Windows (leveraging WSL)

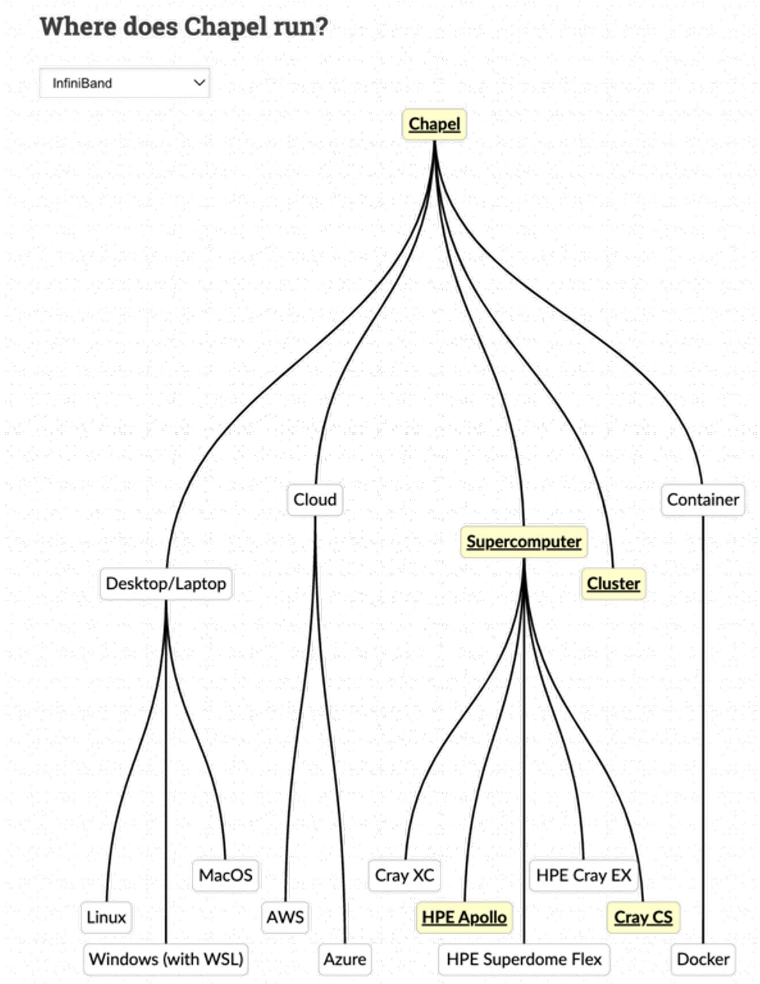
HPC Systems:
- Commodity clusters
- HPE/Cray supercomputers, such as:
  - Frontier
  - Perlmutter
  - Piz Daint
  - Polaris
  - …
- Other vendors' supercomputers

Cloud:
- AWS
- Microsoft Azure

CPUs:
- Intel
- AMD
- Arm (M1/M*, Graviton, A64FX, Raspberry Pi, …)
- RISC-V

GPUs:
- NVIDIA
- AMD

Networks:
- Slingshot
- Aries/Gemini
- InfiniBand
- AWS EFA
- Ethernet



https://chapel-lang.org/docs/usingchapel/portability.html

Where can I get Chapel?

Release Formats:

— Source releases via GitHub

— Spack / E4S

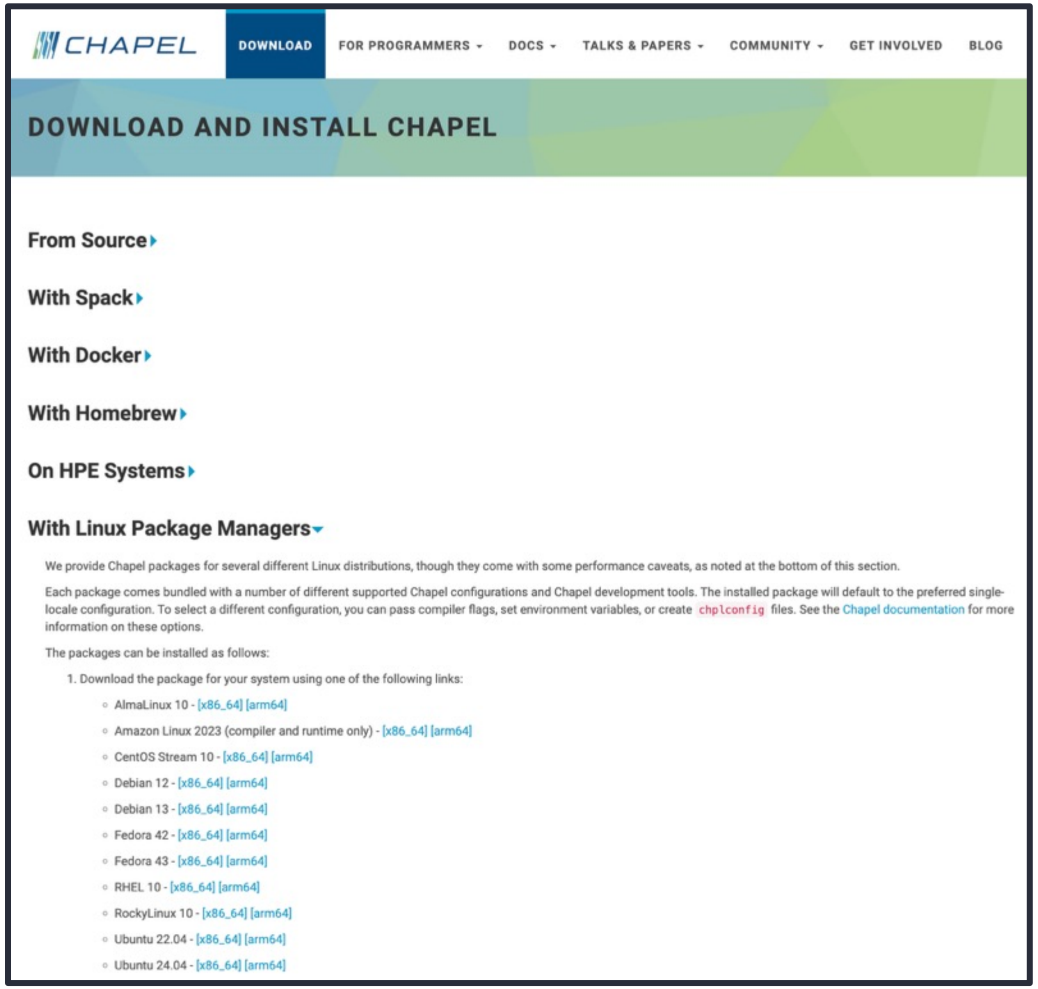
— Docker

— Homebrew

— Modules on HPE Cray EX systems

— Linux packages via apt/rpm

— Attempt This Online / GitHub Codespaces



https://chapel-lang.org/download/

Ways to engage with the Chapel Community

Synchronous Community Events

- Project Meetings, weekly
- Deep Dive / Demo Sessions, weekly timeslot
- ChapelCon (formerly CHIUW), ~~annually~~

Asynchrounous Communications

- Chapel Blog
- Community Newsletter, quarterly
- Announcement Emails, around big events

Social Media

FOLLOW US

- BlueSky
- Facebook
- LinkedIn
- Mastodon
- Reddit
- X (Twitter)
- YouTube

Discussion Forums

GET IN TOUCH

- Discord
- Discourse
- Email
- GitHub Issues
- Gitter
- Slack
- Stack Overflow

Ways to Use Chapel

GET STARTED

- Attempt This Online
- Docker
- E4S
- GitHub Releases
- Homebrew
- Spack

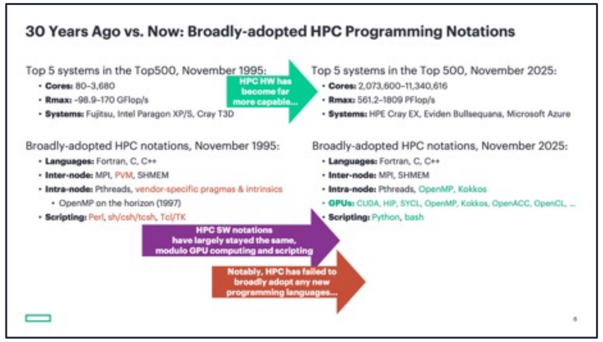
(from the footer of chapel-lang.org)

Closing Thoughts

Summary

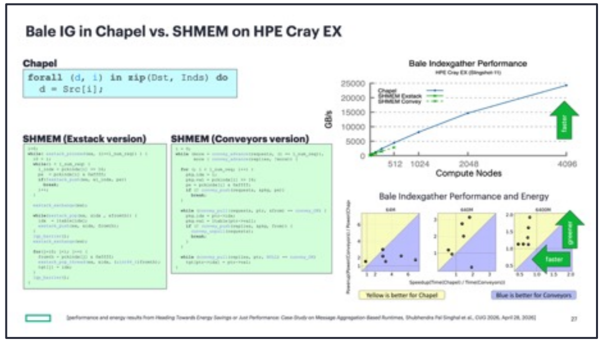
Parallel programming traditionally requires a mix of notations to leverage HW

- e.g., C++ with MPI, OpenMP, and/or CUDA
- such programming models are sufficient, but leave much to be desired
- hardware has generally become more difficult to program over time
  - and at HPC scales, hardware speeds & feeds tend to dominate budgets and attention



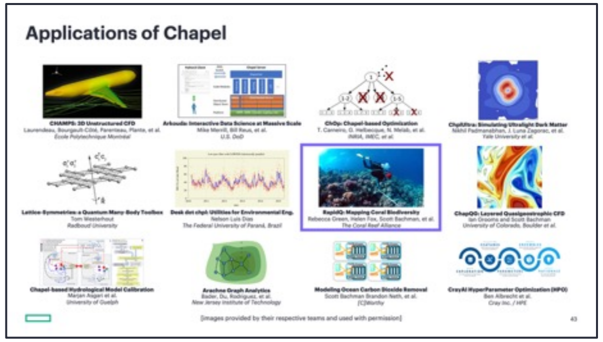
Chapel is a unique parallel language

- high-level features for parallelism and locality
- portable across CPUs, GPUs, networks, vendors, scales, ...
- scalable, performant, energy-efficient(?)
- simplifies compiler optimizations on distributed systems (not discussed today)



Users are benefitting from Chapel, on laptops as well as supercomputers

- Coral Reef image processing
- Computational Fluid Dynamics
- Data Analysis
- ...



Closing Statements

I consider current and aspiring [scalable] parallel programmers
to be at least as worthy of modern languages as the
Python, Rust, Swift, and Julia communities are

Over the next 25 years, I hope we see the number of broadly adopted
languages for scalable parallelism grow to be ≥1, rather than the current 0

AI and Parallel Languages

Q: Now that AIs can program*, do languages like Chapel still have value?

(* = your mileage may vary)

A: I'd say "definitely", at least for the foreseeable future:

- Targeting a single, unified parallel language should be at least as successful as a mash-up of lower-level notations
- Leveraging higher-level abstractions and compiler optimizations conserves tokens by not re-solving problems
- As long as humans need to validate and maintain AI-developed code, the clearer it is the better

Chapel

```
forall (d, i) in zip(Dst, Inds) do
  d = Src[i];
```

SHMEM (Exstack version)

```
i=0;
while( exstack_proceed(ex, (i==l_num_req)) ) {
  i0 = i;
  while(i < l_num_req) {
    l_indx = pckindx[i] >> 16;
    pe  = pckindx[i] & 0xffff;
    if(!exstack_push(ex, &l_indx, pe))
      break;
    i++;
  }

  exstack_exchange(ex);

  while(exstack_pop(ex, &idx , &fromth)) {
    idx  = ltable[idx];
    exstack_push(ex, &idx, fromth);
  }
  lgp_barrier();
  exstack_exchange(ex);

  for(j=i0; j<i; j++) {
    fromth = pckindx[j] & 0xffff;
    exstack_pop_thread(ex, &idx, (uint64_t)fromth);
    tgt[j] = idx;
  }
  lgp_barrier();
}
```

SHMEM (Conveyors version)

```
i = 0;
while (more = convey_advance(requests, (i == l_num_req)),
       more | convey_advance(replies, !more)) {

  for (; i < l_num_req; i++) {
    pkg.idx = i;
    pkg.val = pckindx[i] >> 16;
    pe = pckindx[i] & 0xffff;
    if (! convey_push(requests, &pkg, pe))
      break;
  }

  while (convey_pull(requests, ptr, &from) == convey_OK) {
    pkg.idx = ptr->idx;
    pkg.val = ltable[ptr->val];
    if (! convey_push(replies, &pkg, from)) {
      convey_unpull(requests);
      break;
    }
  }

  while (convey_pull(replies, ptr, NULL) == convey_OK)
    tgt[ptr->idx] = ptr->val;
}
```

Thank You

@ChapelLanguage