Chapel's Multiresolution Programming Model

Mixing High-level Parallel Abstractions with Lower-level Control

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Northwest C++ Users Group

February 21, 2018

Safe Harbor Statement

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What is Chapel?

What is Chapel?

Chapel: A productive parallel programming language

- portable
- open-source
- a collaborative effort

Goals:

- Support general parallel programming
  - "any parallel algorithm on any parallel hardware"
- Make parallel programming at scale far more productive

Scalable Parallel Programming Concerns

Q: What do HPC programmers need from a language?

A: *Serial Code:* Software engineering and performance

Parallelism: What should execute simultaneously?

Locality: Where should those tasks execute?

Mapping: How to map the program to the system?

Separation of Concerns: Decouple these issues

Chapel is a language designed to address these needs from first principles

Chapel and Other Languages

Chapel strives to be as…

…**programmable** as Python

…**fast** as Fortran

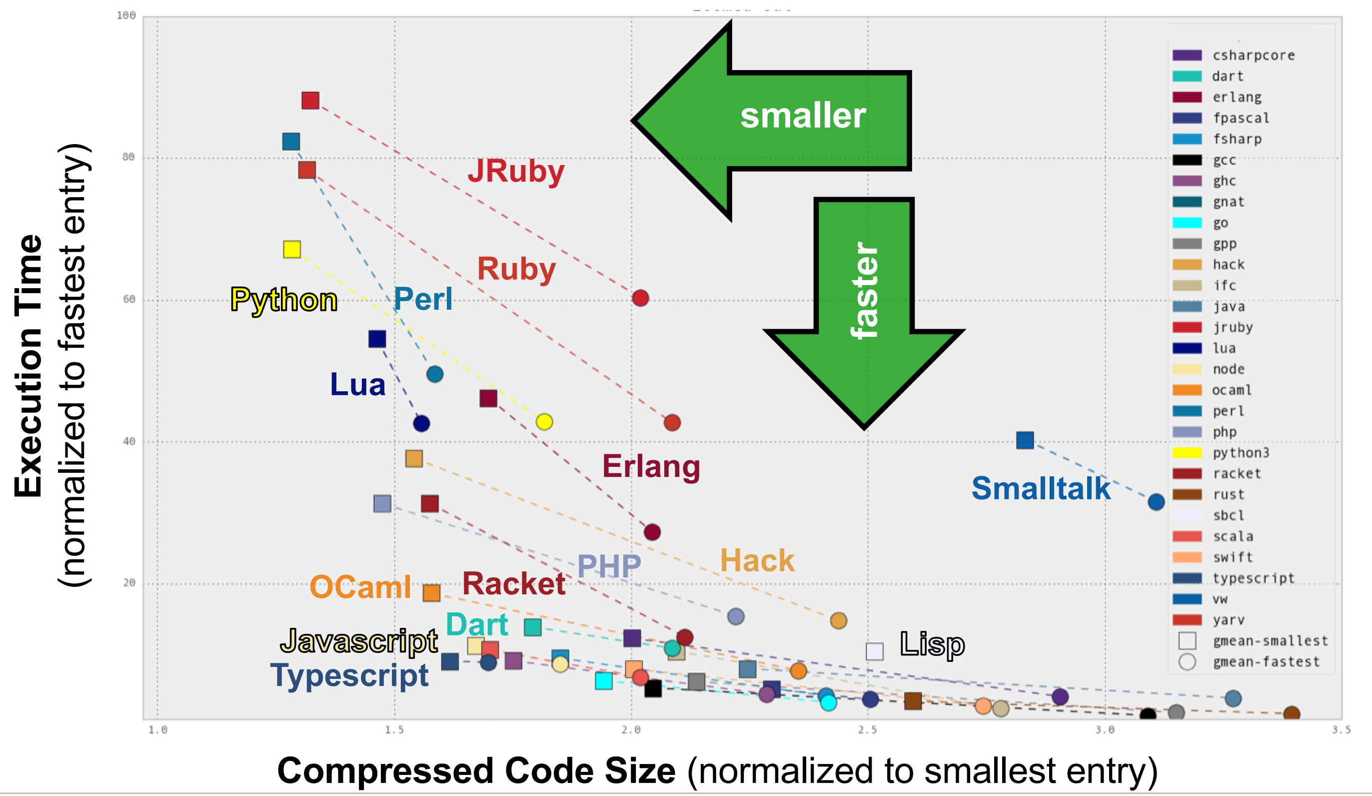
…**scalable** as MPI, SHMEM, or UPC

…**portable** as C

…**flexible** as C++

…**fun** as [your favorite programming language]

CLBG Cross-Language Summary
(Oct 2017 standings)



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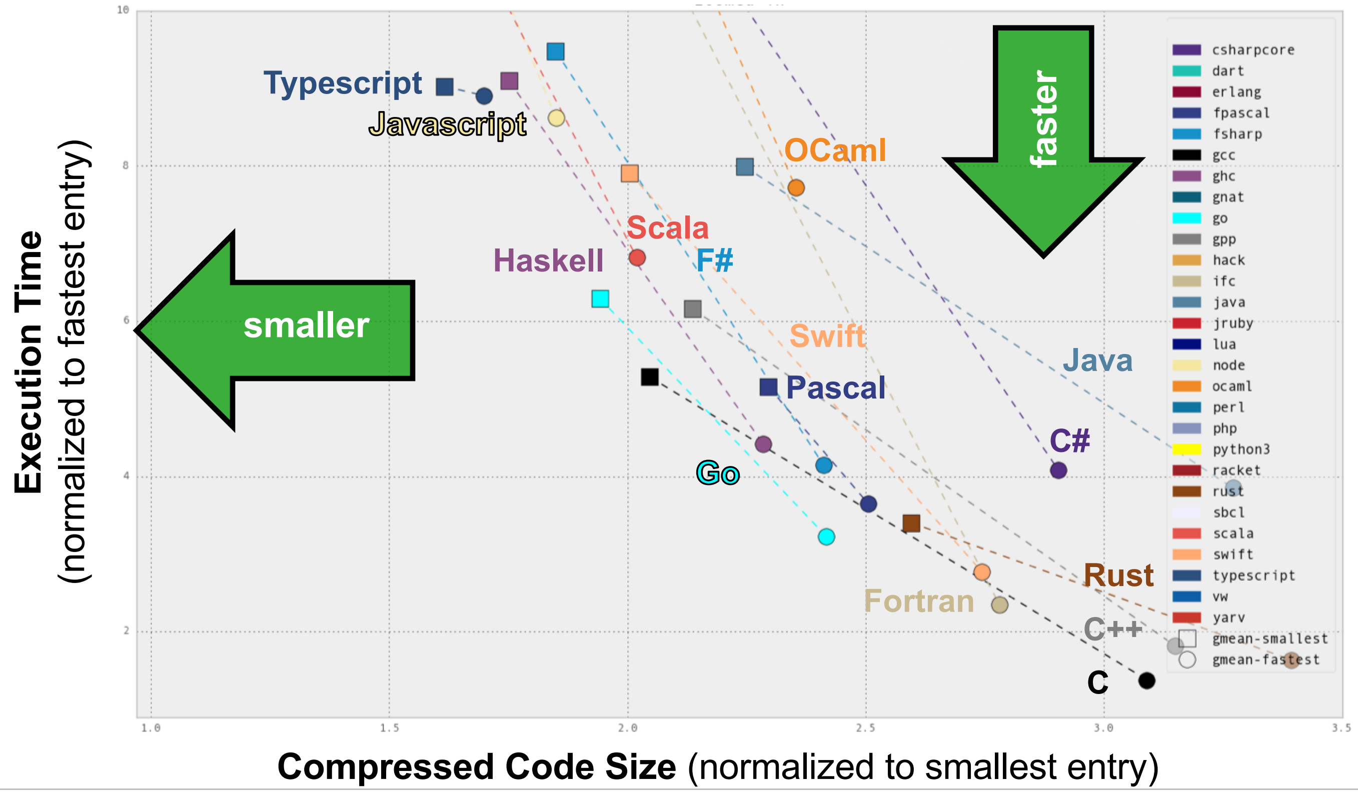
(Oct 2017 standings, zoomed in)



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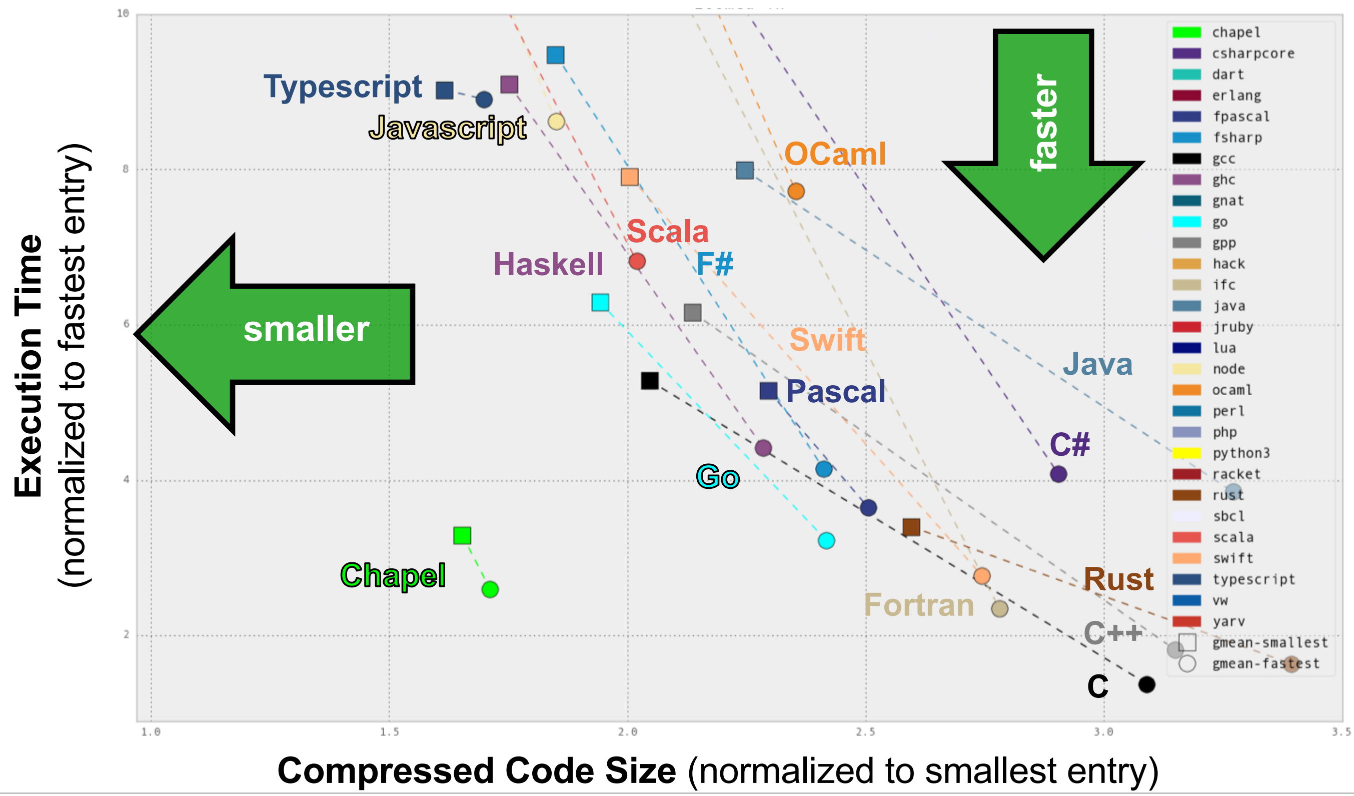

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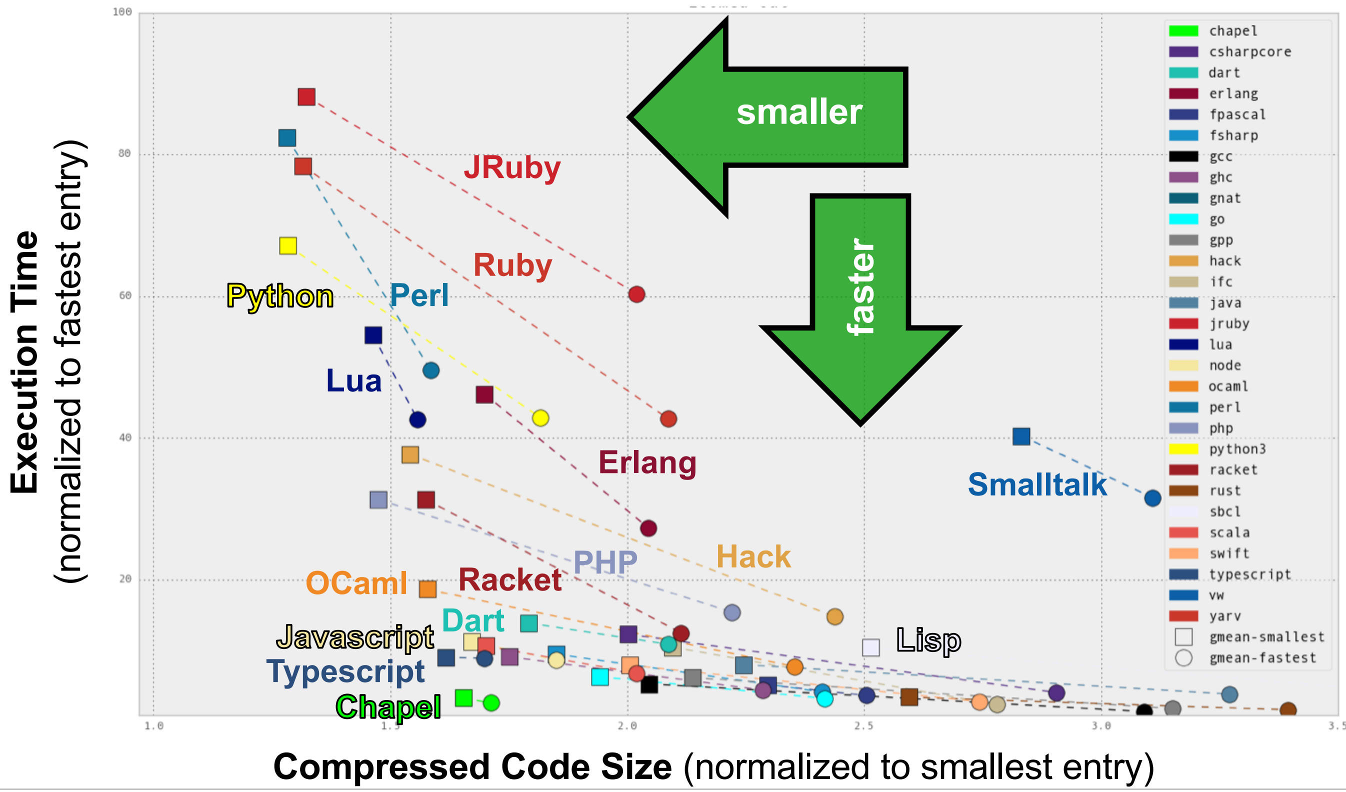
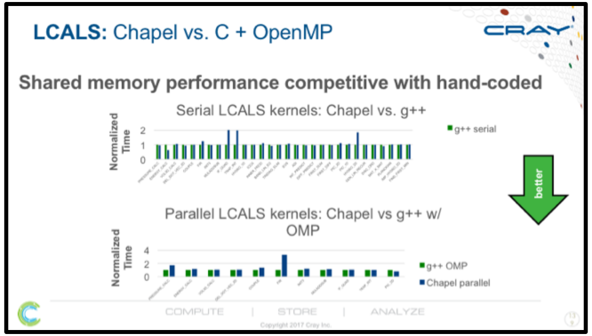
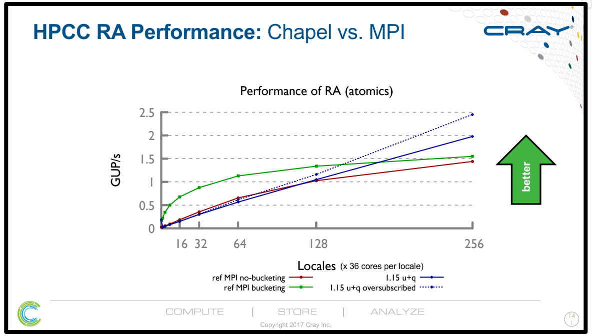


Chapel Performance: HPC Benchmarks



LCALS

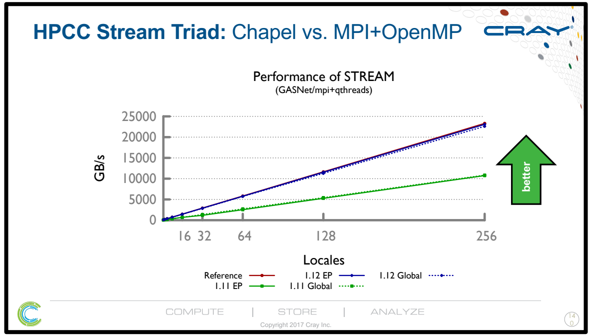
HPCC RA

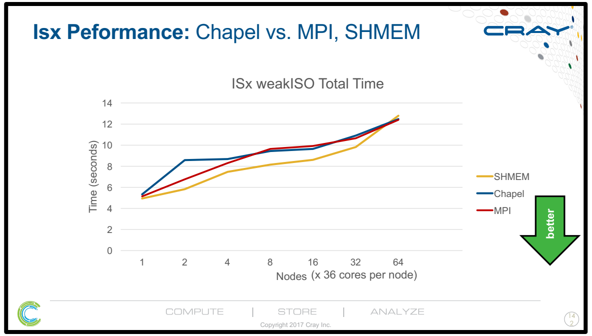


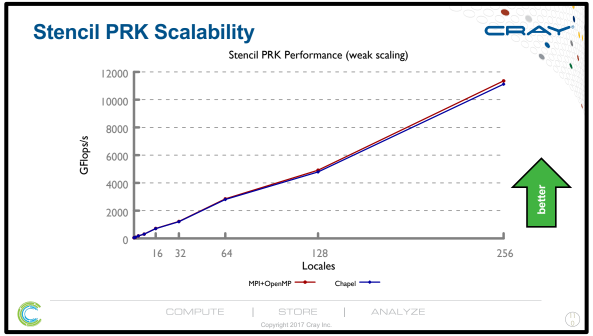
STREAM Triad

ISx

PRK Stencil







Nightly performance graphs online at: https://chapel-lang.org/perf

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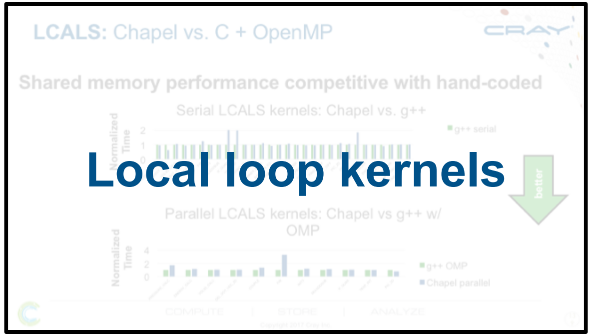

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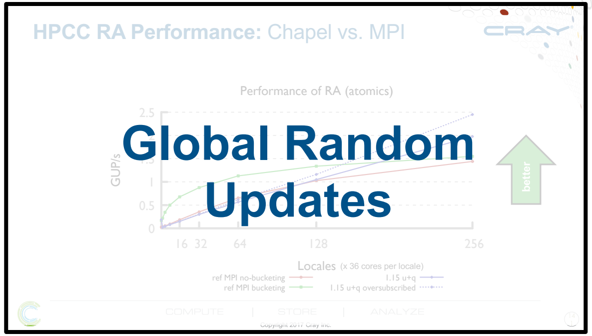

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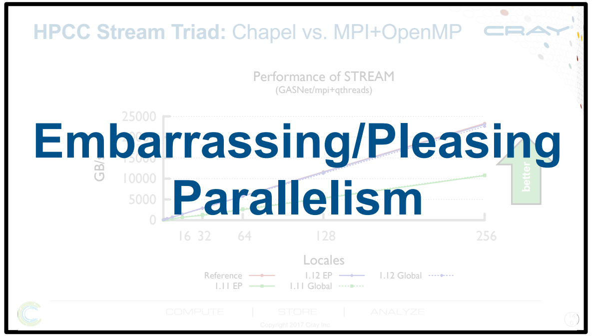
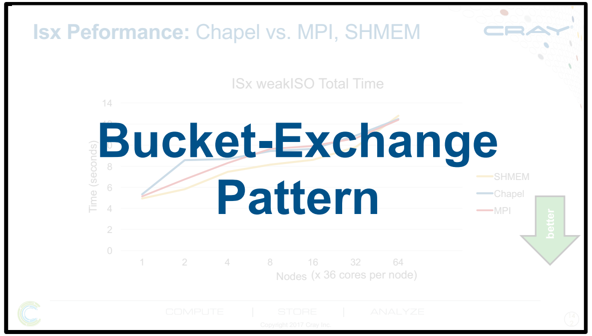
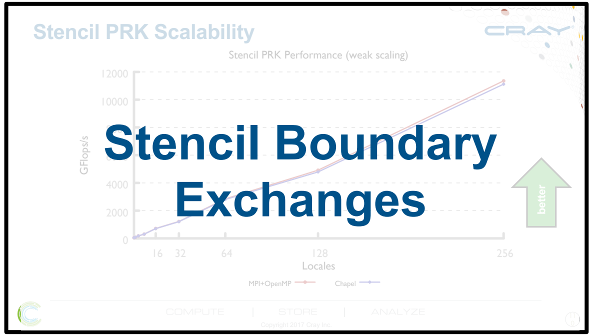






Nightly performance graphs online at: https://chapel-lang.org/perf

The Chapel Team at Cray (May 2017)

14 full-time employees + ~2 summer interns

Chapel Community Partners

HAVERFORD COLLEGE

AMD

THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON, DC

WESTERN WASHINGTON UNIVERSITY

東京大学
THE UNIVERSITY OF TOKYO

THE UNIVERSITY OF ARIZONA

RICE

UNIVERSITY OF MARYLAND

BERKELEY LAB
Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Sandia National Laboratories

DEPARTMENT OF DEFENSE · UNITED STATES OF AMERICA

Yale

(and several others…)

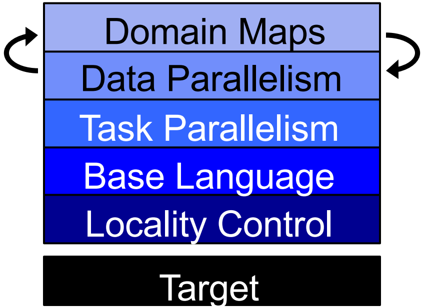
https://chapel-lang.org/collaborations.html

Tonight's Plan

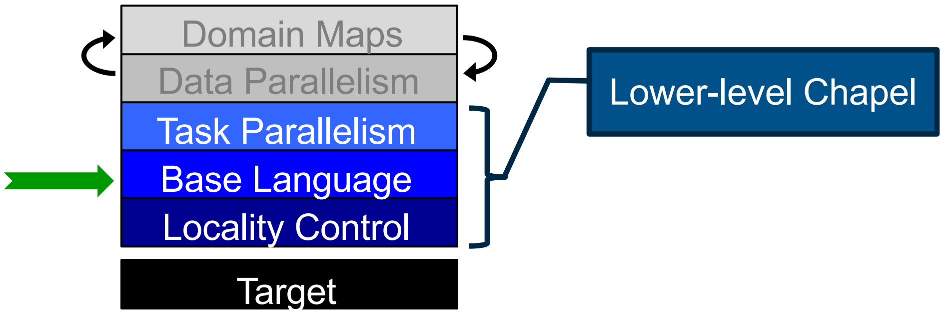
- **Cover features that we haven't in this forum before**
  - base language features of potential interest to C++ users
  - multiresolution features for user control over parallel abstractions
    - parallel iterators
    - domain maps
    - locale models
- **Review core features along the way**
  - goal: quicker than in previous talks
  - help refresh memories / bring new attendees up-to-speed
- **Please ask questions as we go**

Chapel language feature areas

Chapel language concepts



Base Language



Base Language Features, by example

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

Base Language Features, by example

Configuration declarations
(to avoid command-line argument parsing)
`./a.out --n=1000000`

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
2
3
5
8
…
```

Base Language Features, by example

Modern iterators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for f in fib(n) do
  writeln(f);
```

```
0
1
1
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3
5
8
…
```

Base Language Features, by example

Static type inference for:

- arguments
- return types
- variables

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
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  }
}
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```
config const n = 10;

for f in fib(n) do
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```
0
1
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…
```

Base Language Features, by example

Zippered iteration

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
```

```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

Base Language Features, by example

Range types and operators

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
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```
fib #0 is 0
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fib #5 is 5
fib #6 is 8
…
```

Base Language Features, by example

tuples

```
iter fib(n) {
  var current = 0,
      next = 1;

  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
  writeln("fib #", i, " is ", f);
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```
fib #0 is 0
fib #1 is 1
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Base Language Features, by example

```
iter fib(n) {
  var current = 0,
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  for i in 1..n {
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    current <=> next;
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config const n = 10;

for (i,f) in zip(0..#n, fib(n)) do
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```
fib #0 is 0
fib #1 is 1
fib #2 is 1
fib #3 is 2
fib #4 is 3
fib #5 is 5
fib #6 is 8
…
```

Other Base Language Features of Potential Interest to C++ Users

Other Base Language Features: OOP

Two flavors of object-oriented types:

- Value-based:

```
record Circle {
  var radius: real;
  proc area() { … }
}
```

- Reference-based:

```
class Circle {
  var radius: real;
  proc area() { … }
}
```

```
var myCircle = new Circle(radius = 1.0),
    myCircle2 = myCircle;     // copy for record, alias for class
myCircle.radius = 2.0;
writeln(myCircle2.area());    // 1.0 for record, 4.0 for class
```

Other Base Language Features: Generics

- **Support for generic types and functions**
  - w.r.t. types and statically known values (`param`s)

```
class Arr {
  param numDims: int;          // number of dimensions
  type eltType;                // element type
  var size: numDims*int;       // tuple storing per-dimension size
}

var myArr  = new Arr(2, string, (100, 200)),
    myArr2 = new Arr(3, real, (500, 500, 500));
```

Other Base Language Features: Generics

- **Support for generic types and functions**
  - w.r.t. types and statically known values (`param`s)

```
proc mypow(type t, x: t, param exponent: int) {
  var result = 1:t;
  for param i in 1..exponent do
    result *= x;
  return result;
}

var twoSquared = mypow(int, 2, 2);
var piCubed = mypow(real, 3.14159265, 3);
```

note: this is an utterly artificial and over-engineered way to write this function in Chapel, done merely to demonstrate type/param args in ~6 lines…

Other Base Language Features: Meta-Programming

- **Compile-time procedures to compute types / params**

```
proc computePacketSize(type t1, type t2) param {
  return numBits(t1) + numBits(t2);
}
proc c_intToChapelInt() type {
  return int(numBits(c_int));
}
```

  - Also, support for config types / params

```
config param bitsPerInt = 16;
config type eltType = int(bitsPerInt);
```

```
chpl -sbitsPerInt=64 -seltType=real(32) myProg.chpl
```

Other Base Language Features: Meta-Programming

- **Ability to unroll loops / fold conditionals or ‘void’ exprs**

```
for param i in (1, 2.3, “hello”, (5,7)) do
  writeln(“i: ” , i, “ has type: ”, i.type:string);
```

- **Reflection module:**
  - “Can this function / method be resolved”
  - “Iterate over all fields in this record giving me their names / types”
  - …

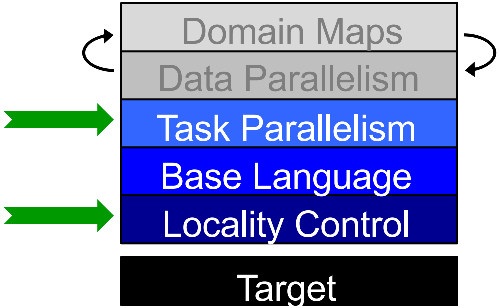
Other Base Language Features

- Error-handling
- Modules (namespaces)
- Overloading, filtering
- Default args, arg intents, keyword-based arg passing
- Argument type queries / pattern-matching
- …

Base Language Features: What's Missing?

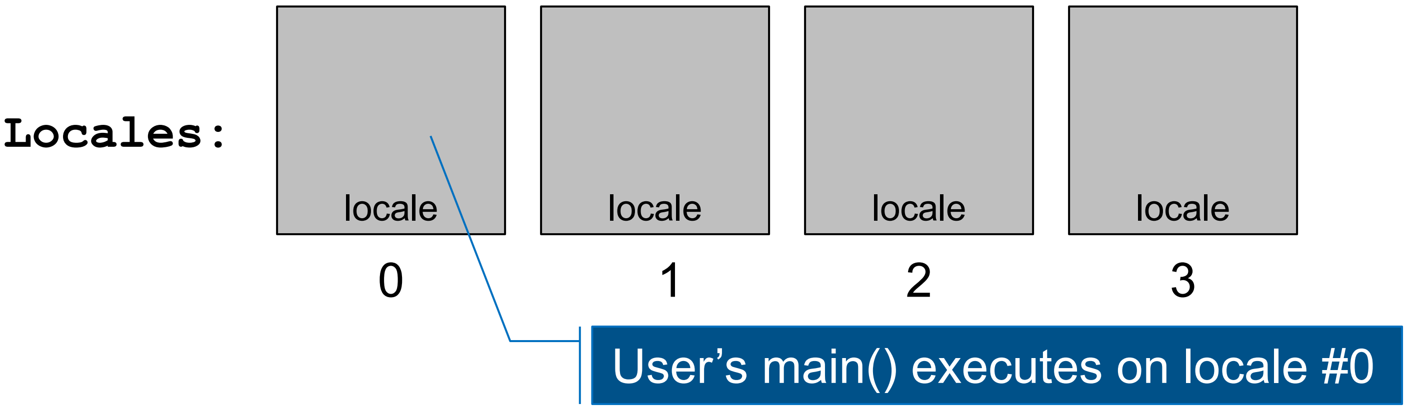
- **better initializer (constructor) features**
  - currently being implemented and refined
- **delete-free programming / borrow-checking**
  - currently being designed and implemented
- **first-class functions**
  - prototyped, need strengthening
- **constrained generics / interfaces / concepts**
  - proposal drafted but not implemented
- **anti-function hijacking features**
  - currently under consideration

Task Parallelism and Locality Control



Locales

- Unit of the target system useful for reasoning about locality
  - Each locale can run tasks and store variables
    - Has processors and memory (or can defer to something that does)
  - For most HPC systems, locale == compute node



Task Parallelism and Locality, by example

taskParallel.chpl

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

```
prompt> chpl taskParallel.chpl -o taskParallel
prompt> ./taskParallel --numLocales=2
Hello from task 1 of 2 running on n1033
Hello from task 2 of 2 running on n1032
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```

Task Parallelism and Locality, by example

Abstraction of System Resources

taskParallel.chpl

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Task Parallelism and Locality, by example

High-Level
Task Parallelism

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```

Control of Locality/Affinity

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Task Parallelism and Locality, by example

Abstraction of System Resources

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Task Parallelism and Locality, by example

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             tid, numTasks, here.name);
  }
```

Not seen here:

Data-centric task coordination via atomic and full/empty vars

```
prompt> chpl taskParallel.chpl -o taskParallel
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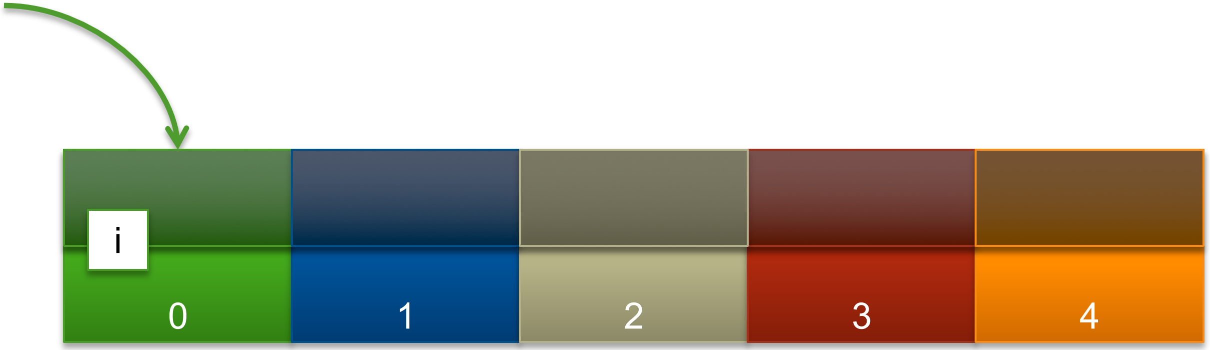
Hello from task 1 of 2 running on n1032
```

Chapel: Scoping and Locality

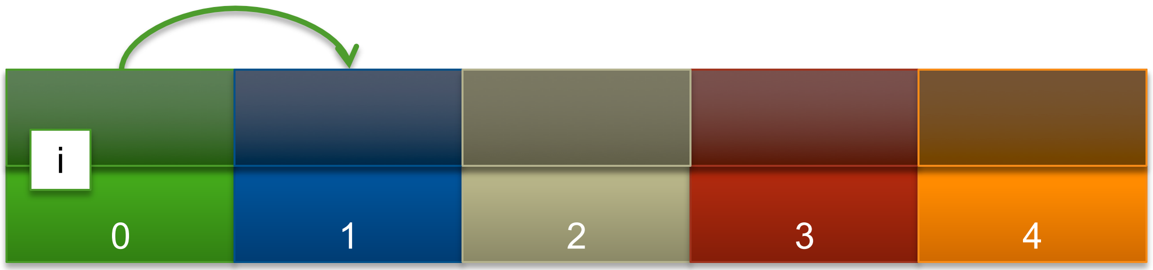
```
var i: int;
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

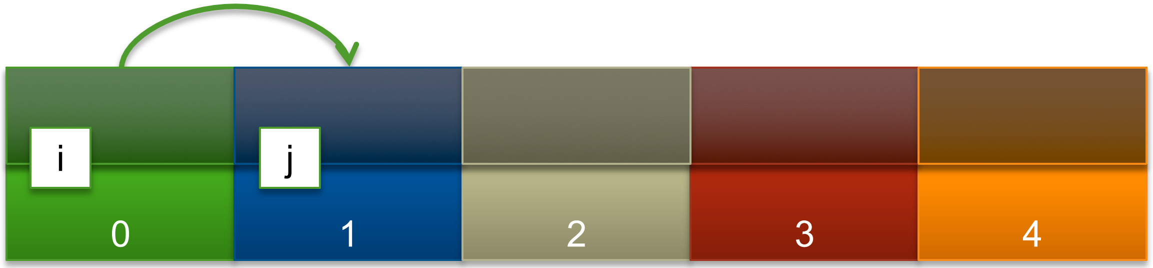
```
var i: int;
on Locales[1] {
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

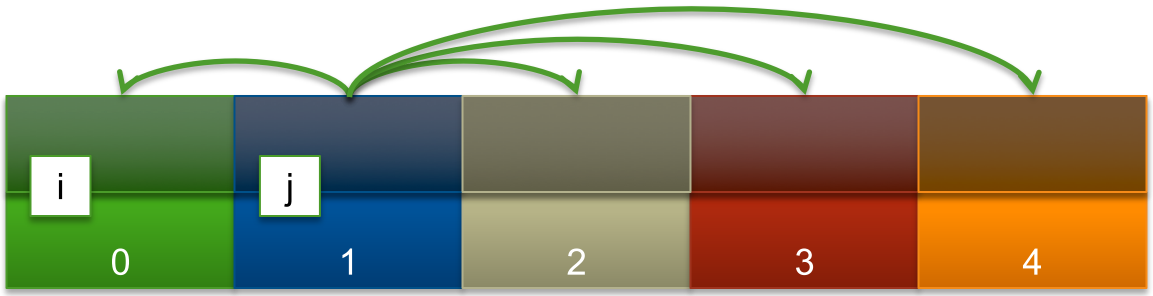
```
var i: int;
on Locales[1] {
  var j: int;
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

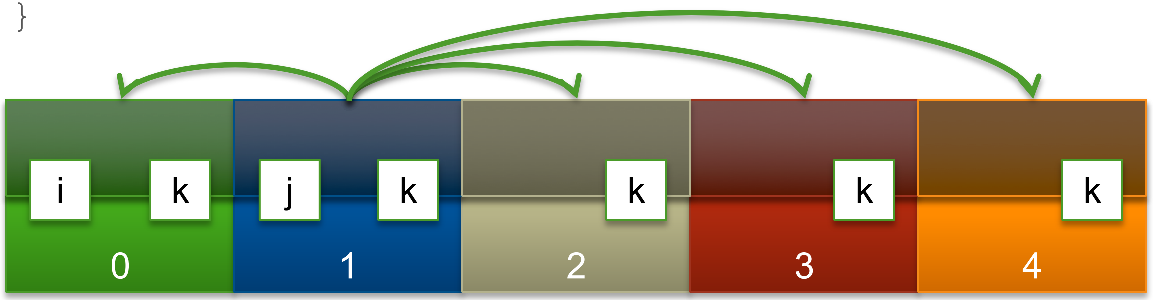
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

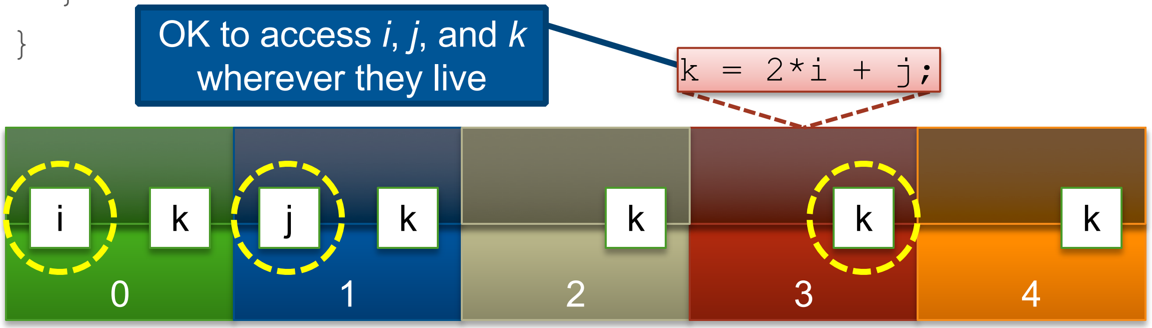
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      …
    }
  }
}
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      var k: int;
      k = 2*i + j;
    }
  }
}
```



Locales (think: "compute nodes")

Chapel: Scoping and Locality

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var i: int;
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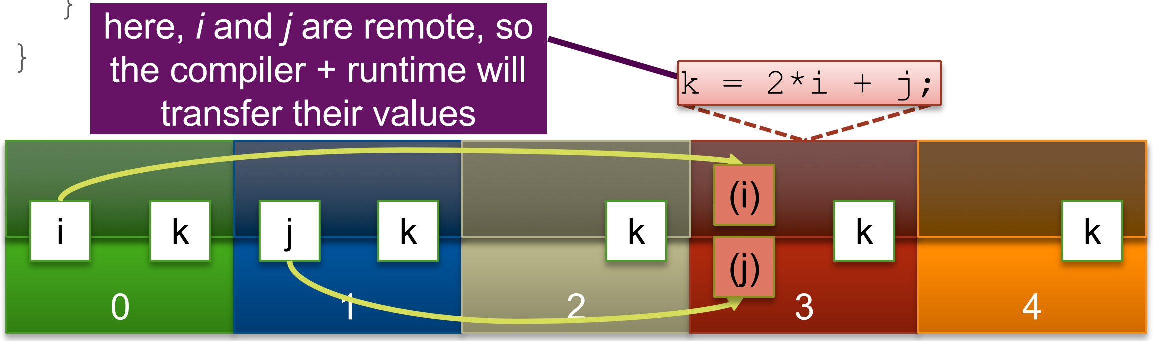
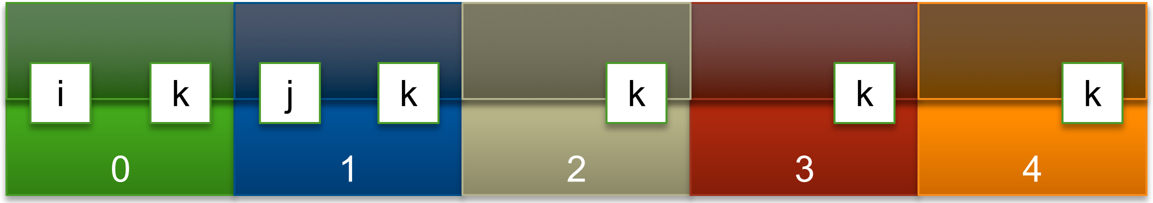


Locales (think: "compute nodes")

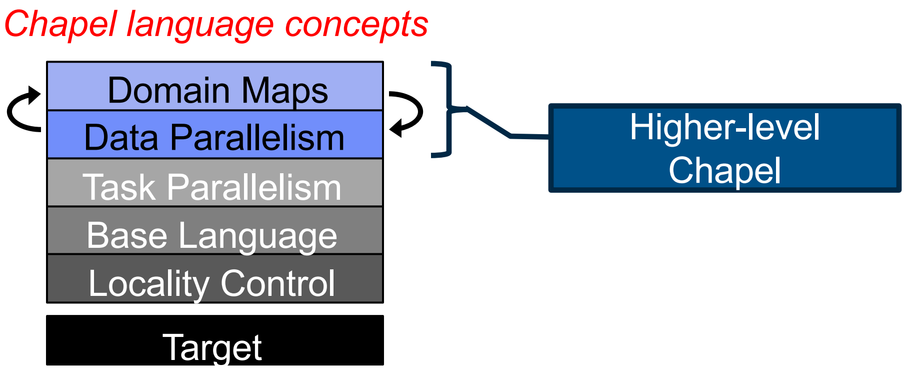
Chapel: Locality queries

```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
      …here…              // query the locale on which this task is running
      …j.locale…          // query the locale on which j is stored
      …here.physicalMemory(…)…  // query system characteristics
      …here.runningTasks()…     // query runtime characteristics
    }
}
```



Locales (think: “compute nodes”)

Data Parallelism in Chapel



Data Parallelism, by example

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Data Parallelism, by example

Domains (Index Sets)

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
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5.1 5.3 5.5 5.7 5.9
```

Data Parallelism, by example

Arrays

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
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4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Data Parallelism, by example

Data-Parallel Forall Loops

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
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writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
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```

Data Parallelism, by example

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
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writeln(A);
```

This is a shared memory program

Nothing has referred to remote locales, explicitly or implicitly

```
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```

Data Parallelism, by example

dataParallel.chpl

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config const n = 1000;
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4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Distributed Data Parallelism, by example

Domain Maps
(Map Data Parallelism to the System)

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
          dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

```
prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5 --numLocales=4
1.1 1.3 1.5 1.7 1.9
2.1 2.3 2.5 2.7 2.9
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Distributed Data Parallelism, by example

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
          dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

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prompt> chpl dataParallel.chpl -o dataParallel
prompt> ./dataParallel --n=5 --numLocales=4
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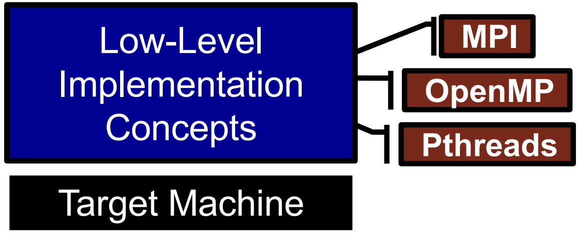
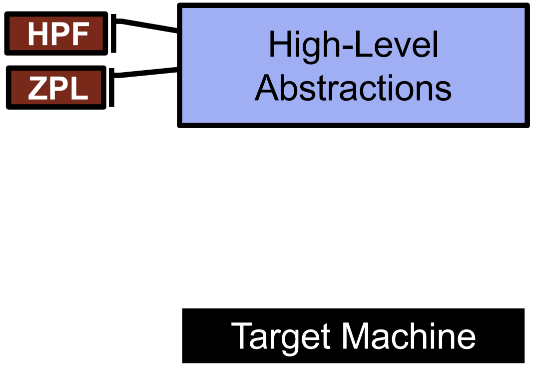
3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Not at all…

- Lowering of code is well-defined
- User can control details
- Part of Chapel's *multiresolution philosophy…*

Chapel's Multiresolution Design: Motivation





"Why is everything so tedious/difficult?"

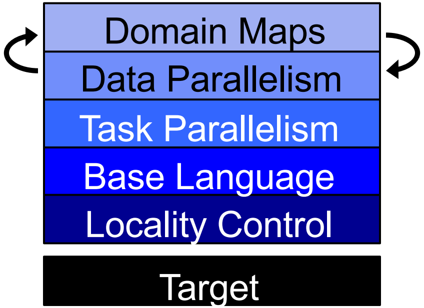
"Why don't my programs trivially port to new systems?"

"Why don't I have more control?"

Chapel's Multiresolution Philosophy

Multiresolution Design: **Support multiple tiers of features**

- higher levels for programmability, productivity
- lower levels for greater degrees of control



- build the higher-level concepts in terms of the lower
- permit users to intermix layers arbitrarily

Distributed Data Parallelism, by example

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ invoke and inline D's default parallel iterator

- defined by D's type / domain map

default domain map

- create a task per local core
- block indices across tasks

dataParallel.chpl

```
config const n = 1000;
var D = {1..n, 1..n};

var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

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3.1 3.3 3.5 3.7 3.9
4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Distributed Data Parallelism, by example

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ invoke and inline D's default parallel iterator

- defined by D's type / domain map

default domain map

cyclic domain map

on each target locale…

- create a task per core
- block local indices across tasks

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
          dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
writeln(A);
```

```
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4.1 4.3 4.5 4.7 4.9
5.1 5.3 5.5 5.7 5.9
```

Distributed Data Parallelism, by example

Chapel's prescriptive approach:

```
forall (i,j) in D do…
```

⇒ in… d… domain map

dataParallel.chpl

```
use CyclicDist;
config const n = 1000;
var D = {1..n, 1..n}
          dmapped Cyclic(startIdx = (1,1));
var A: [D] real;
forall (i,j) in D do
  A[i,j] = i + (j - 0.5)/n;
```

```
…rallel.chpl -o dataParallel
…lel --n=5 --numLocales=4
```

- Write and call your own parallel iterator:

```
forall (i,j) in myParIter(D) do…
```

- Or, use a different domain map:

```
var D = {1..n, 1..n} dmapped Block(…);
```

- Or, write and use your own domain map:

```
var D = {1..n, 1..n} dmapped MyDomMap(…);
```

Write and Call Your Own Parallel Iterator

Authoring Parallel Iterators

- **Similar to serial iterators, but invoked by `forall` loops**
  - Unlike serial iterators, these can contain parallel constructs

```
forall i in myParIter(D) { … }
```

invokes:

```
iter myParIter(dom: domain, … /* tag as a parallel iterator */) {
  coforall tid in 0..#numTasks {
    const myChunk = computeChunk(dom, tid, numTasks);
    for i in myChunk do
      yield i;
  }
}
```

Authoring Zippered Parallel Iterators

- Parallel iterators can also support zippered iteration

```
forall (i,j) in zip(myParIter(D), A) { … }
```

  - defined in terms of leader…

```
iter myParIter(dom: domain, …) {
  coforall tid in 0..#numTasks do
    yield computeChunk(dom, tid, numTasks);
}
```

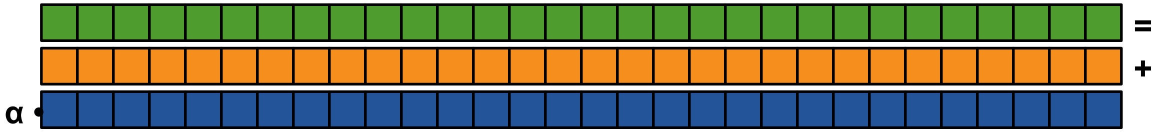
…and follower iterators:

```
iter myParIter(dom: domain, followThis, …) {
  for i in followThis do yield i;
}
```

Use a Different Domain Map

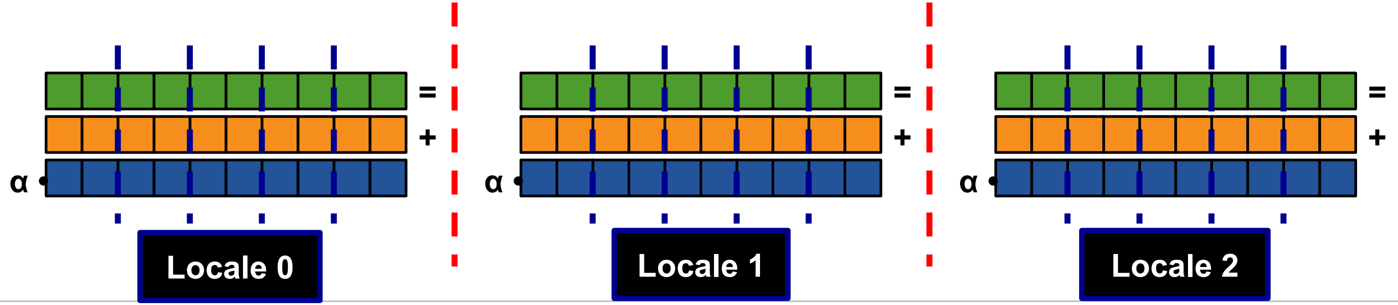
Domain Maps: A Multiresolution Feature

Domain maps are "recipes" that instruct the compiler how to map the global view of a computation…



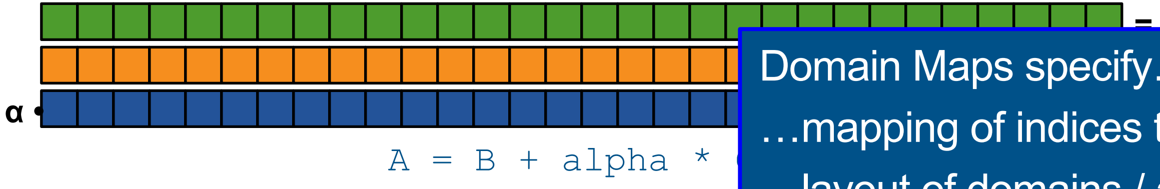

```
A = B + alpha * C;
```

…to the target locales' memory and processors:

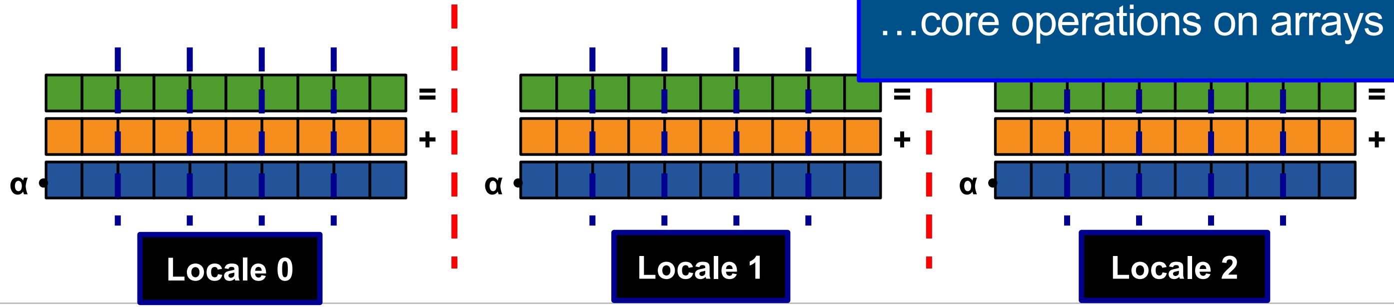


Domain Maps: A Multiresolution Feature

Domain maps are "recipes" that instruct the compiler how to map the global view of a computation…



…to the target locales' memory and processors:



Domain Maps specify…

…mapping of indices to locales

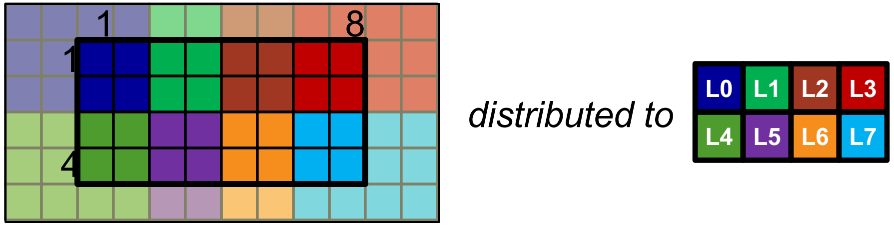
…layout of domains / arrays in memory

…parallel iteration strategies

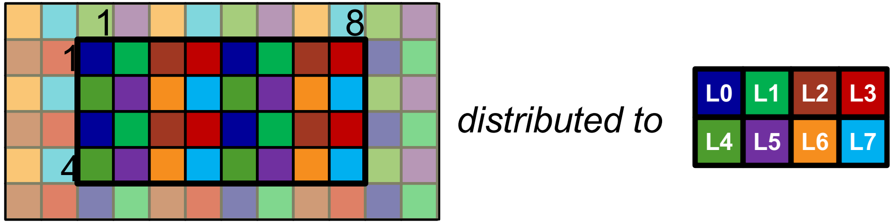
…core operations on arrays / domains

Sample Domain Maps: Block and Cyclic

```
var Dom = {1..4, 1..8} dmapped Block( {1..4, 1..8} );
```



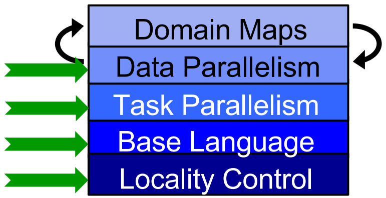

```
var Dom = {1..4, 1..8} dmapped Cyclic( startIdx=(1,1) );
```



Write and Use Your Own Domain Map

Chapel's Domain Map Philosophy

1. **Chapel provides a library of standard domain maps**
   - to support common array implementations effortlessly
2. **Expert users can write their own domain maps in Chapel**
   - to cope with any shortcomings in our standard library



3. **Chapel's standard domain maps are written using the end-user framework**
   - to avoid a performance cliff between "built-in" and user-defined cases
   - in fact *every* Chapel array is implemented using this framework

Domain Map Descriptors

Domain Map

Represents: a domain map value

Generic w.r.t.: index type

State: the domain map's representation

Typical Size: Θ(1) → Θ(*numLocales*)

Required Interface:
- create new domains
- which locale owns index *i*?

Domain

Represents: a domain

Generic w.r.t.: index type

State: representation of index set

Typical Size: Θ(1) → Θ(*numIndices*)

Required Interface:
- create new arrays
- queries: size, members
- iterators: serial, parallel
- domain assignment
- index set operations

Array

Represents: an array

Generic w.r.t.: index type, element type

State: array elements

Typical Size: Θ(*numIndices*)

Required Interface:
- (re-)allocation of elements
- random access
- iterators: serial, parallel
- get/set of sparse "zero" values
- …

Chapel and Performance Portability

- **Avoid locking key policy decisions into the language**
  - Array memory layout?
  - Sparse storage format?
  - Parallel loop policies?

Chapel and Performance Portability

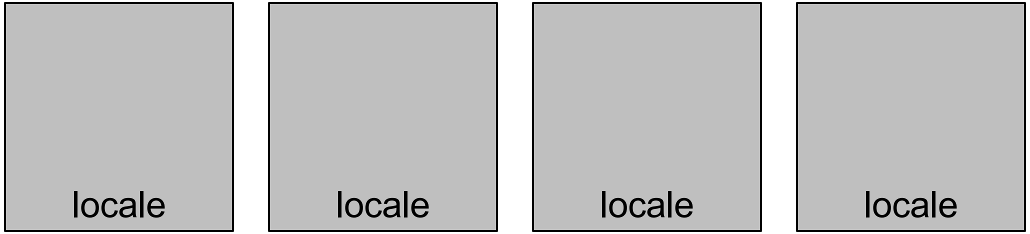
- **Avoid locking key policy decisions into the language**
  - Array memory layout? **not defined by Chapel**
  - Sparse storage format? **not defined by Chapel**
  - Parallel loop policies? **not defined by Chapel**
  - Abstract node architecture? **not defined by Chapel**
- **Instead, permit users to specify these in Chapel itself**
  - support performance portability through…

    …a separation of concerns

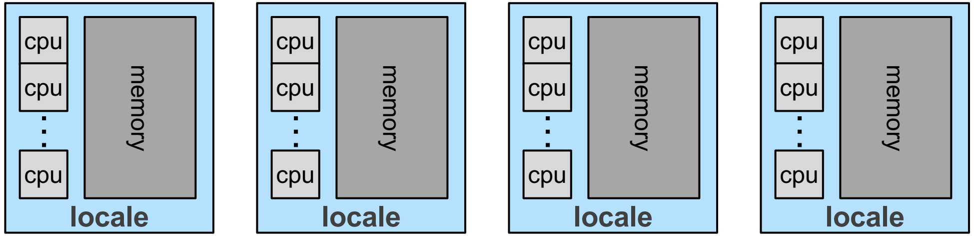
    …abstractions—known to the compiler, and therefore optimizable
  - **goal:** make Chapel a future-proof language

Classic Locales

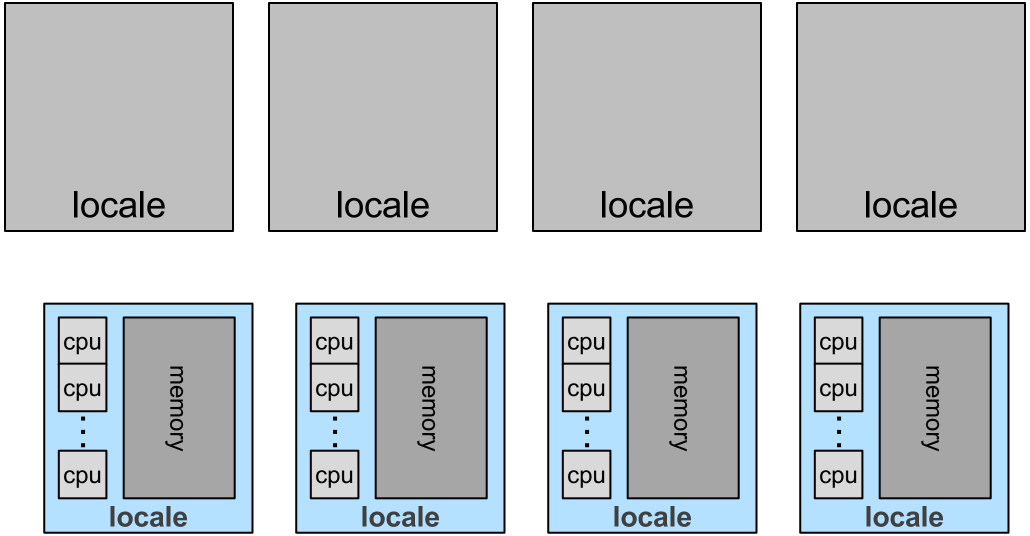
- **Historically, Chapel's locales were black boxes**
  - Intra-node concerns handled by compiler, runtime, OS



  - This was sufficient when compute nodes were simple

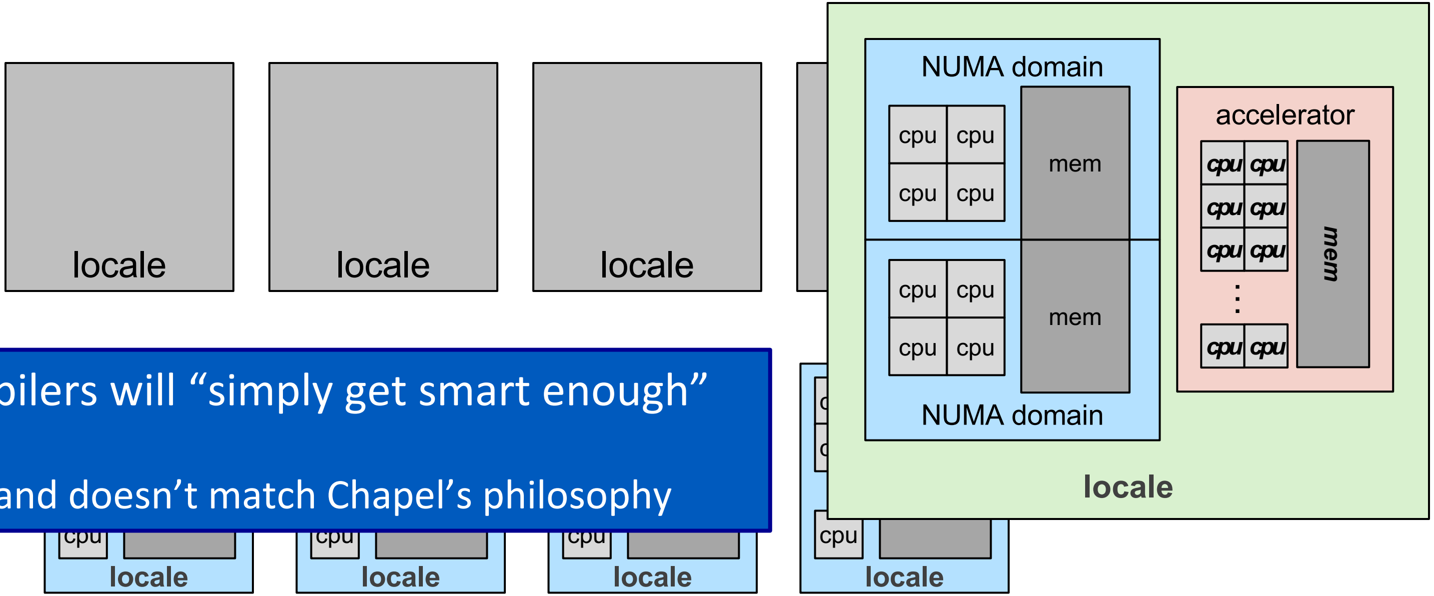


Classic Locales



Classic Locales

- **Classic model breaks down for more complex cases**
  - E.g. multiple flavors of memory or processors

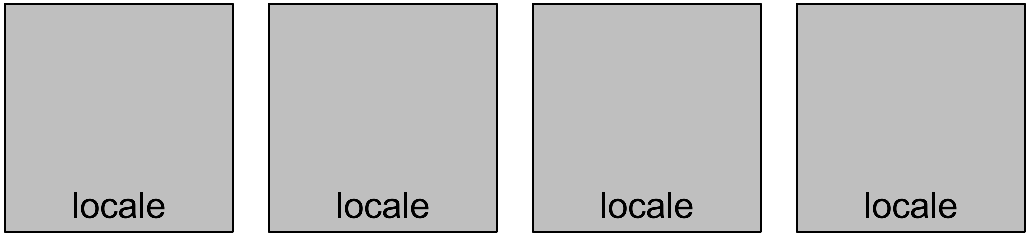


Could hope compilers will "simply get smart enough"

…but seems naïve and doesn't match Chapel's philosophy

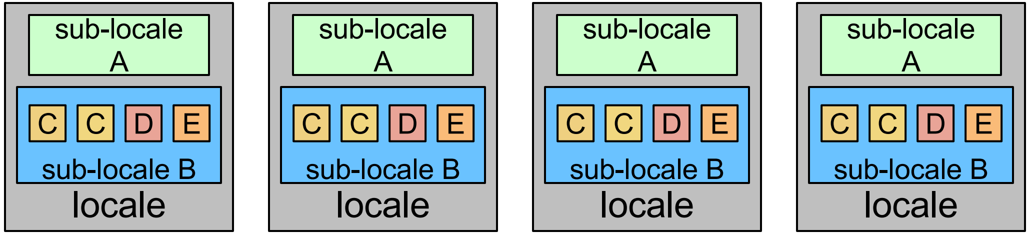
Hierarchical Locales

- So, we made locales hierarchical



Hierarchical Locales

- **So, we made locales hierarchical**
  - Locales can now themselves contain locales
    - E.g., an accelerator sub-locale, a scratchpad memory sub-locale



  - Target sub-locales with on-clauses, as before

```
on Locales[0].GPU do computationThatLikesGPUs();
```

    - Ideally, hide such logic in abstractions: domain maps, parallel iterators
  - Introduced a new multiresolution type: *locale models*

Chapel's Locale Models

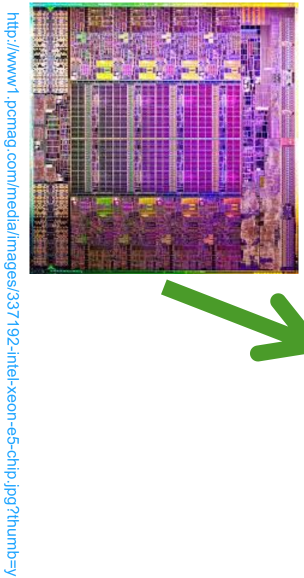
- **User-specified type representing locales**
- **Similar goals to domain maps:**
  - Support user implementation of key high-level abstractions
  - Make language future-proof (w.r.t. emerging architectures)

Authoring a Locale Model

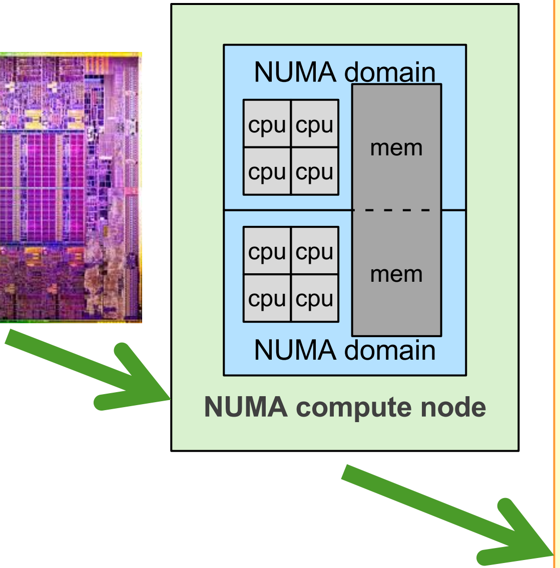
- **Creating a locale model:**
  - Create a top-level locale object type
    - In turn, it can contain fields representing sub-locales
  - Each locale / sub-locale type must meet a required interface:
    - **Memory:** How is it managed? (malloc, realloc, free)
    - **Tasking:** How do I launch and synchronize tasks?
    - **Communication:** How are data & control transferred between locales?
      - gets, puts, active messages
      - widening of pointers

An Example: The numa Locale Model

physical



conceptual



$CHPL_HOME/modules/…/numa/LocaleModel.chpl

```
class NumaDomain : AbstractLocaleModel {
  const sid: chpl_sublocID_t;
}

// The node model
class LocaleModel : AbstractLocaleModel {
  const numSublocales: int;
  var childSpace: domain(1);
  var childLocales: [childSpace] NumaDomain;
}

// support for memory management
proc chpl_here_alloc(size:int, md:int(16)) { … }

// support for "on" statements
proc chpl_executeOn
     (loc: chpl_localeID_t, // target locale
      fn: int,              // on-body func idx
      args: c_void_ptr,     // func args
      args_size: int(32)    // args size
     ) { … }

// support for tasking stmts: begin, cobegin, coforall
proc chpl_taskListAddCoStmt
     (subloc_id: int,        // target subloc
      fn: int,               // body func idx
      args: c_void_ptr,      // func args
      ref tlist: _task_list, // task list
      tlist_node_id: int     // task list owner
     ) { … }
```

Locale Models: Status

- **All Chapel compilations use a locale model**
  - Set via environment variable or compiler flag
- **Current locale models:**
  - **flat**: the default, has no sublocales (as in the classic model)
  - **numa:** supports a sub-locale per NUMA domain within the node
  - **knl:** for Intel® Xeon Phi™: numa w/ sublocale for HBM/MCDRAM

Wrapping Up

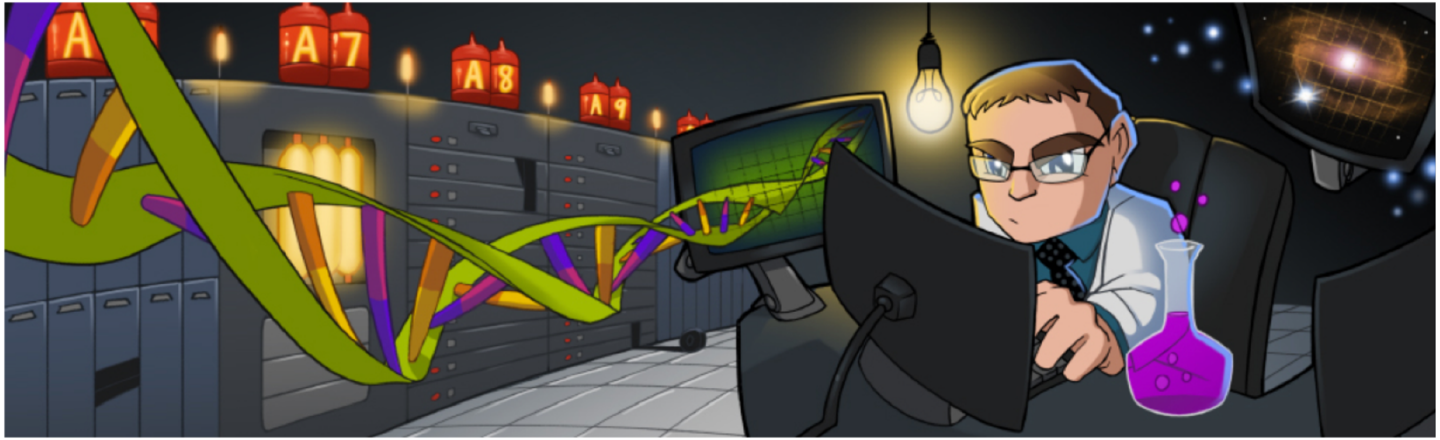
Summary

- **Chapel's design uses a multiresolution philosophy**
  - High-level for productivity
  - Low-level for control
  - User-extensible for flexibility, future-proof design
- **Three key examples of multiresolution features:**
  - **Parallel iterators:** specify the implementation of forall loops
  - **Domain maps:** specify the implementation of domains and arrays
  - **Locale models:** specify the capabilities of the target architecture

CHIUW 2017 Keynote

Chapel's Home in the Landscape of New Scientific Computing Languages
(and what it can learn from the neighbours)

Jonathan Dursi, *The Hospital for Sick Children, Toronto*



Quote from CHIUW 2017 keynote

"My opinion as an outsider…is that Chapel is important, Chapel is mature, and Chapel is just getting started.

"If the scientific community is going to have frameworks for solving scientific problems that are actually designed for our problems, they're going to come from a project like Chapel.

"And the thing about Chapel is that the set of all things that are 'projects like Chapel' is 'Chapel.'"

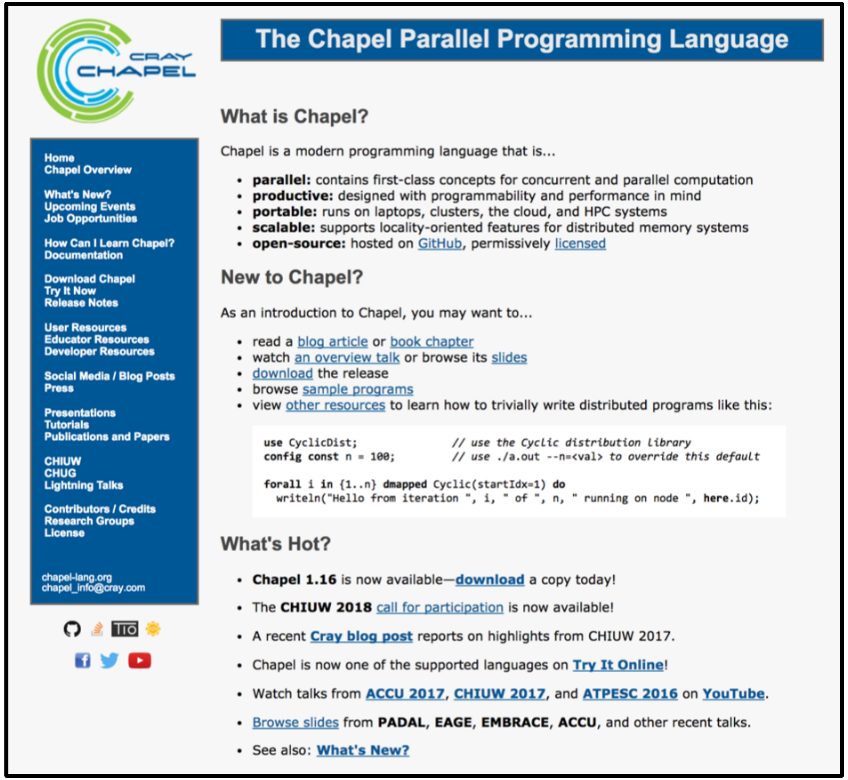
–Jonathan Dursi

Chapel's Home in the New Landscape of Scientific Frameworks
(and what it can learn from the neighbours)
CHIUW 2017 keynote

https://ljdursi.github.io/CHIUW2017 / https://www.youtube.com/watch?v=xj0rwdLOR4U

Chapel Resources

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


CRAY CHAPEL

The Chapel Parallel Programming Language

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chapel-lang.org
chapel_info@cray.com

What is Chapel?

Chapel is a modern programming language that is...

- **parallel:** contains first-class concepts for concurrent and parallel computation
- **productive:** designed with programmability and performance in mind
- **portable:** runs on laptops, clusters, the cloud, and HPC systems
- **scalable:** supports locality-oriented features for distributed memory systems
- **open-source:** hosted on GitHub, permissively licensed

New to Chapel?

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

- read a blog article or book chapter
- watch an overview talk or browse its slides
- download the release
- browse sample programs
- view other resources to learn how to trivially write distributed programs like this:

```
use CyclicDist;              // use the Cyclic distribution library
config const n = 100;        // use ./a.out --n=<val> 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);
```

What's Hot?

- **Chapel 1.16** is now available—**download** a copy today!
- The **CHIUW 2018** call for participation is now available!
- A recent **Cray blog post** reports on highlights from CHIUW 2017.
- Chapel is now one of the supported languages on **Try It Online**!
- Watch talks from **ACCU 2017**, **CHIUW 2017**, and **ATPESC 2016** on **YouTube**.
- Browse slides from **PADAL**, **EAGE**, **EMBRACE**, **ACCU**, and other recent talks.
- See also: **What's New?**

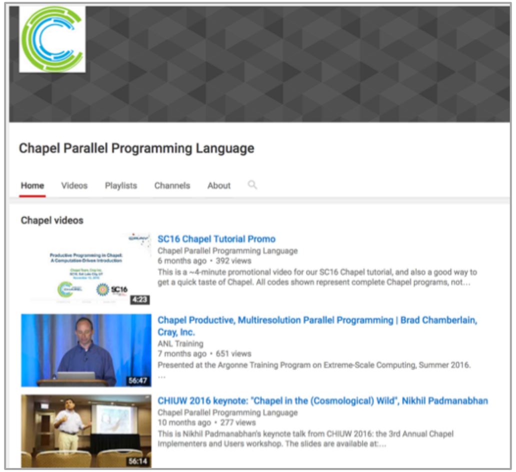
How to Track Chapel

http://facebook.com/ChapelLanguage

http://twitter.com/ChapelLanguage

https://www.youtube.com/channel/UCHmm27bYjhknK5mU7ZzPGsQ/

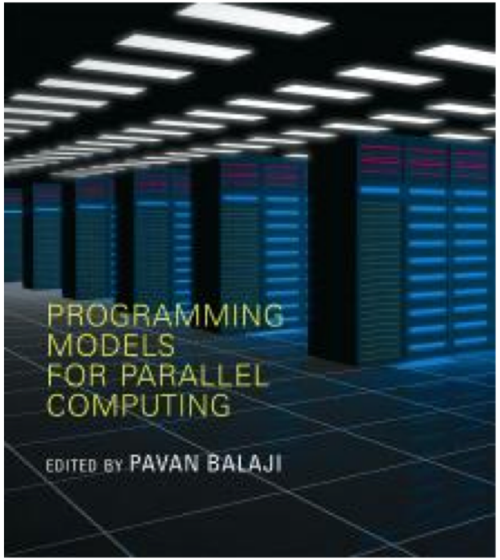
chapel-announce@lists.sourceforge.net



Suggested Reading (healthy attention spans)

Chapel chapter from ***Programming Models for Parallel Computing***

- a detailed overview of Chapel's history, motivating themes, features
- published by MIT Press, November 2015
- edited by Pavan Balaji (Argonne)
- chapter is now also available online



Other Chapel papers/publications available at **https://chapel-lang.org/papers.html**

Suggested Reading (short attention spans)

CHIUW 2017: Surveying the Chapel Landscape, Cray Blog, July 2017.

- *a run-down of recent events*

Chapel: Productive Parallel Programming, Cray Blog, May 2013.

- *a short-and-sweet introduction to Chapel*

Six Ways to Say "Hello" in Chapel **(parts 1, 2, 3)**, Cray Blog, Sep-Oct 2015.

- *a series of articles illustrating the basics of parallelism and locality in Chapel*

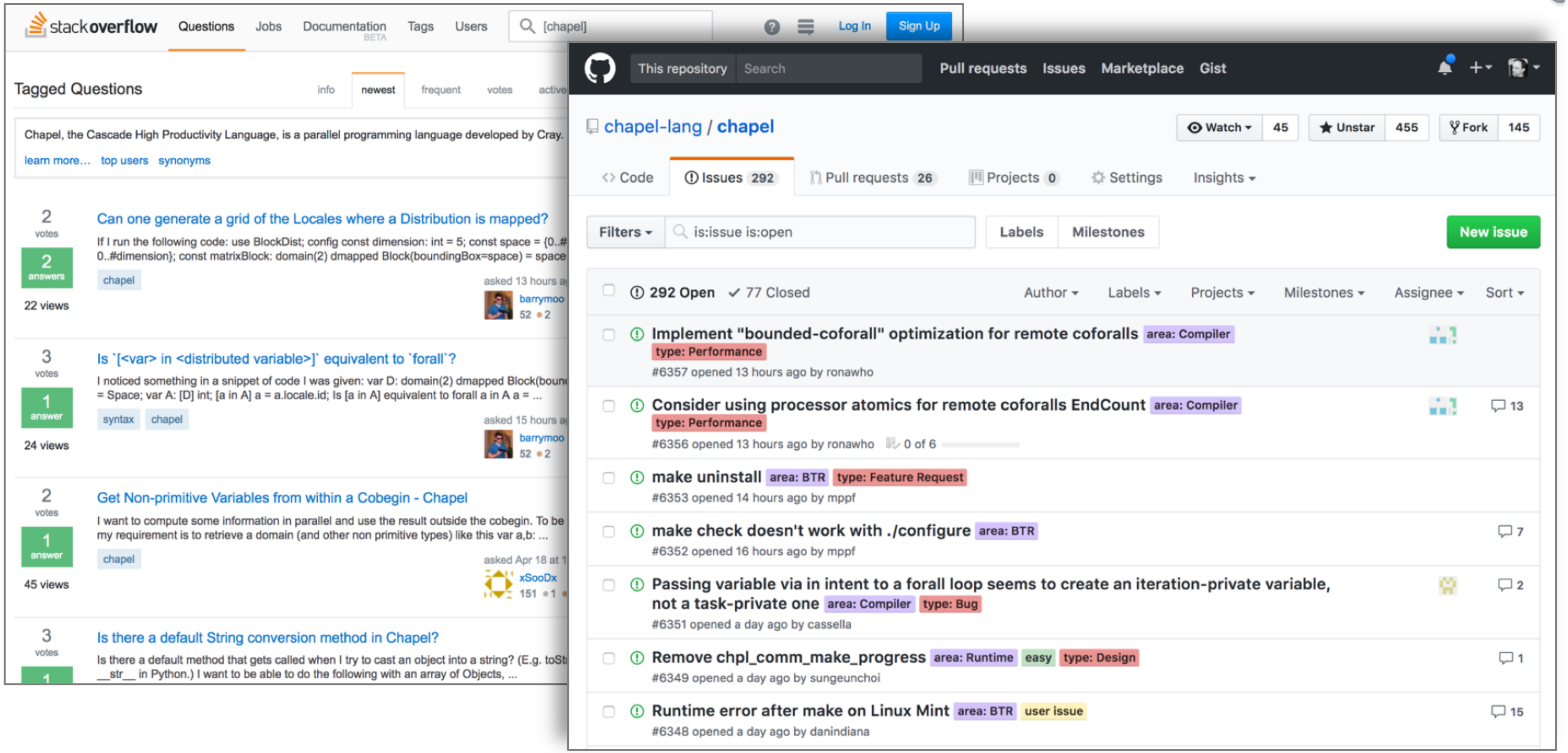
Why Chapel? **(parts 1, 2, 3)**, Cray Blog, Jun-Oct 2014.

- *a series of articles answering common questions about why we are pursuing Chapel in spite of the inherent challenges*

[Ten] Myths About Scalable Programming Languages, IEEE TCSC Blog (index available on chapel-lang.org "blog posts" page), Apr-Nov 2012.

- *a series of technical opinion pieces designed to argue against standard reasons given for not developing high-level parallel languages*

Chapel StackOverflow and GitHub Issues



Where to..

Submit bug reports:

- GitHub issues for chapel-lang/chapel: public bug forum
- chapel_bugs@cray.com: for reporting non-public bugs

Ask User-Oriented Questions:

- StackOverflow: when appropriate / other users might care
- #chapel-users (irc.freenode.net): user-oriented IRC channel
- chapel-users@lists.sourceforge.net: user discussions

Discuss Chapel development

- chapel-developers@lists.sourceforge.net: developer discussions
- #chapel-developers (irc.freenode.net): developer-oriented IRC channel

Discuss Chapel's use in education

- chapel-education@lists.sourceforge.net: educator discussions

Directly contact Chapel team at Cray: chapel_info@cray.com

Questions?

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