Chapel:
An Emerging Parallel Programming Language

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Northwest C++ Users' Group

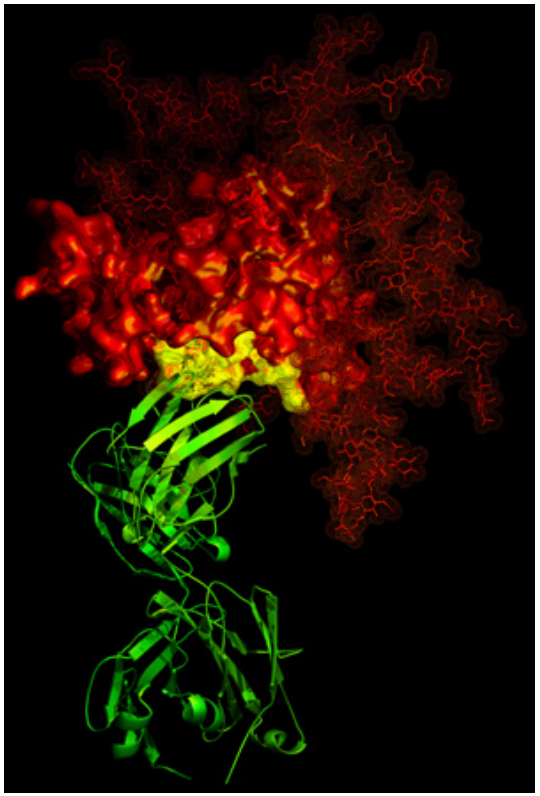
April 16th, 2014

My Employer:

CRAY
THE SUPERCOMPUTER COMPANY

Parallel Challenges

Genome Sequencing
Photo: umn.edu



Virus modeling
Photo: HPCWire.com

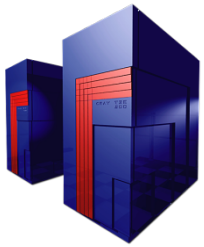
Square-Kilometer Array
Photo: www.phy.cam.ac.uk

https://en.wikipedia.org/wiki/Human_Genome_Project
http://archive.hpcwire.com/hpcwire/2013-06-03/researchers_tap_cray_super_to_decode_hiv-i_interior.html
http://www.hpcwire.com/2013/12/12/supercomputing-fundamental-ska-project/

Hardware Progression

- 1988: 8 Processors - 512 MB memory

- 1998: 1,024 Processors - 1 TB memory



- 2008: 150,000 Processors - 360 TB memory

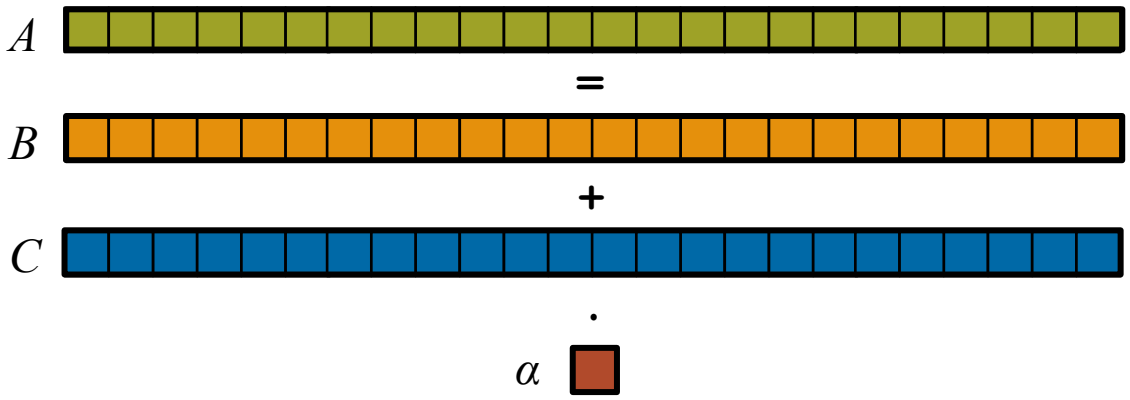
- 2020: 10,000,000 Processors? - ? memory

A trivial parallel computation

Given: m-element vectors A, B, C

Compute: $\forall i \in 1..m,\ A_i = B_i + \alpha \cdot C_i$

In pictures:



A trivial parallel computation

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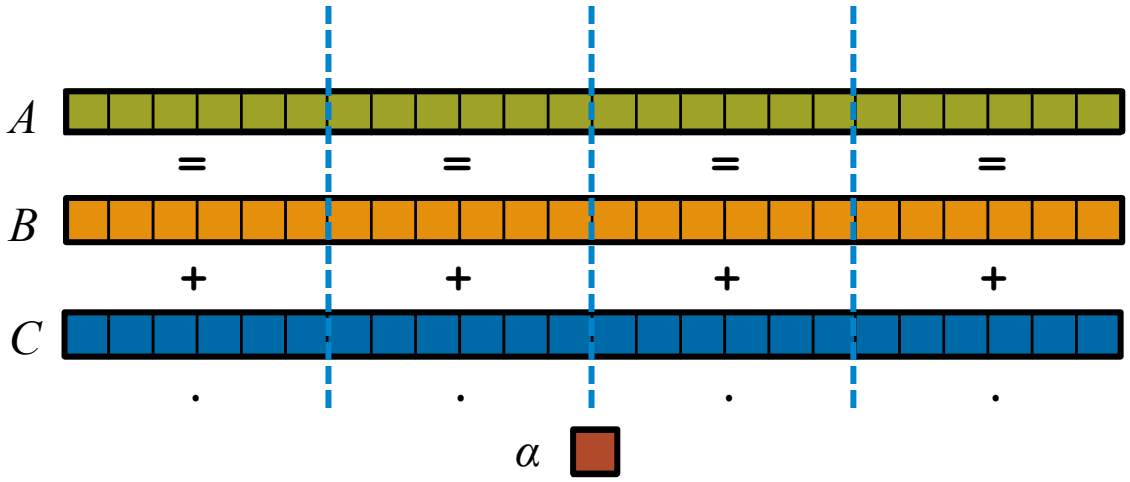
In pictures, in parallel:

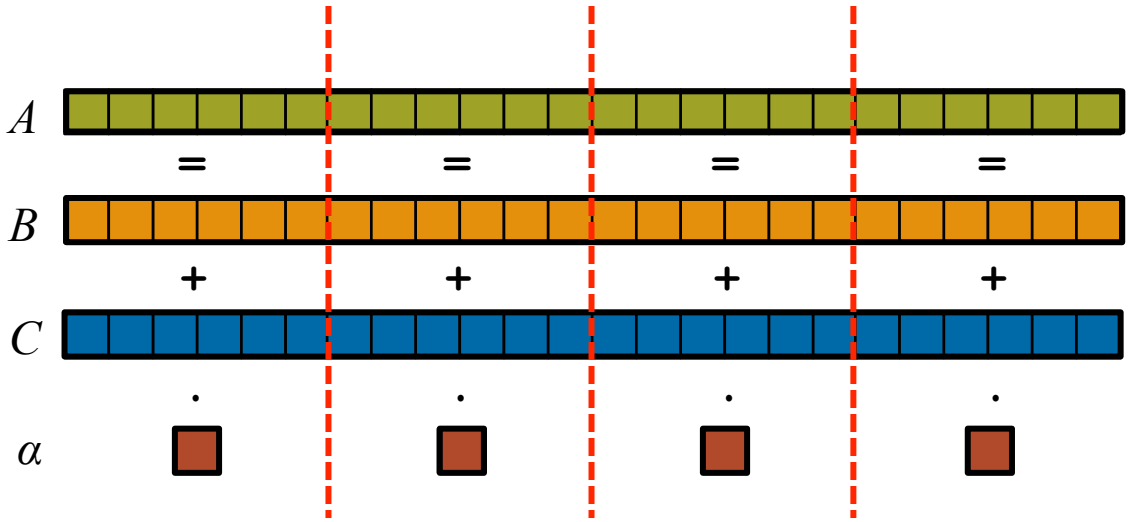


A trivial parallel computation

Given: m-element vectors A, B, C

Compute: $\forall i \in 1..m,\ A_i = B_i + \alpha \cdot C_i$

In pictures, in parallel (distributed memory):

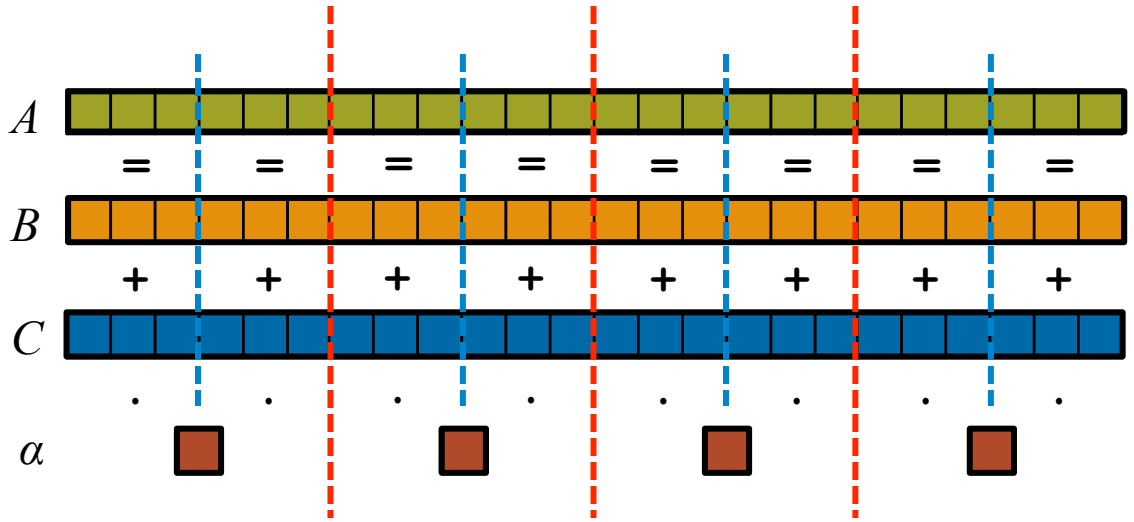


A trivial parallel computation

Given: m-element vectors A, B, C

Compute: $\forall i \in 1..m,\ A_i = B_i + \alpha \cdot C_i$

In pictures, in parallel (distributed memory multicore):



Existing programming models?

- MPI – C, Fortran, Java
- CUDA, OpenACC for GPUs

- MapReduce
- Custom solutions

Limitations:

- Closely tied to hardware.
- Support single type of parallelism.

What is Chapel?

- **An emerging parallel programming language**
  - Design and development led by Cray Inc.
- **A work-in-progress**
- **Chapel's overall goal: Improve programmer productivity**

Chapel's Implementation

- **Open source at SourceForge**
  - Moving to Github soon!
- **BSD license**
- **Target Architectures:**
  - multicore desktops and laptops
  - commodity clusters and the cloud
  - supercomputers
- **Compiler and runtime written in C++/C**
- **Standard library and language features written in Chapel**

Chapel Community

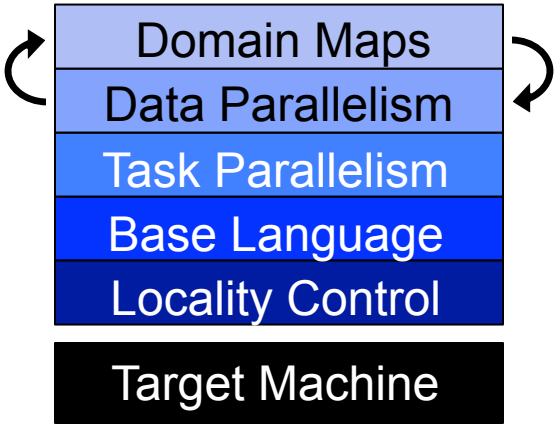
Users:

- 1000+ downloads of each release
- 200 subscribers to chapel-users mailing list

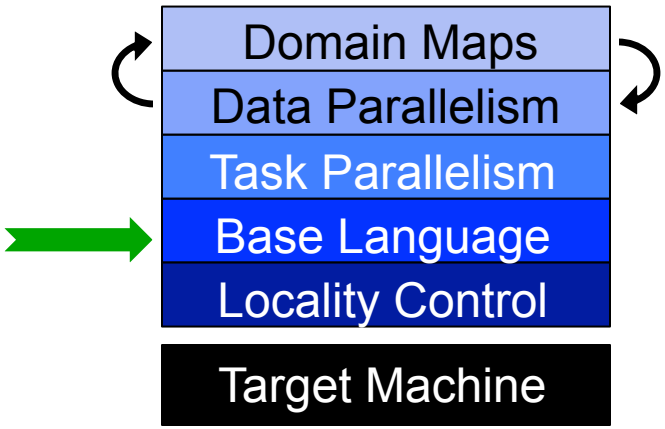
Developers (last release):

- 19 developers
- 8 organizations
- 5 countries

Multiresolution Design



Base Language Features



Static Type Inference

```
const pi = 3.14,              // pi is a real
      coord = 1.2 + 3.4i,     // coord is a complex…
      coord2 = pi*coord,      // …as is coord2
      name = "foo",           // name is a string
      verbose = false;        // verbose is boolean

proc addem(x, y) {            // addem() has generic arguments
  return x + y;               //   and an inferred return type
}

var sum = addem(1, pi),                 // sum is a real
    fullname = addem(name, "bar");      // fullname is a string

writeln((sum, fullname));
```

```
(4.14, foobar)
```

Range Types and Algebra

```
const r = 1..10;

printVals(r # 3);
printVals(r by 2);
printVals(r by -2);
printVals(r by 2 # 3);
printVals(r # 3 by 2);
printVals(0.. #n);

proc printVals(r) {
  for i in r do
    write(i, " ");
  writeln();
}
```

```
1 2 3
1 3 5 7 9
10 8 6 4 2
1 3 5
1 3
0 1 2 3 4 … n-1
```

Iterators

```
iter fibonacci(n) {
  var current = 0,
      next = 1;
  for i in 1..n {
    yield current;
    current += next;
    current <=> next;
  }
}
```

```
for f in fibonacci(7) do
  writeln(f);
```

```
0
1
1
2
3
5
8
```

Zippered Iteration

```
for (i,f) in zip(0..#n, fibonacci(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
…
```

Classes

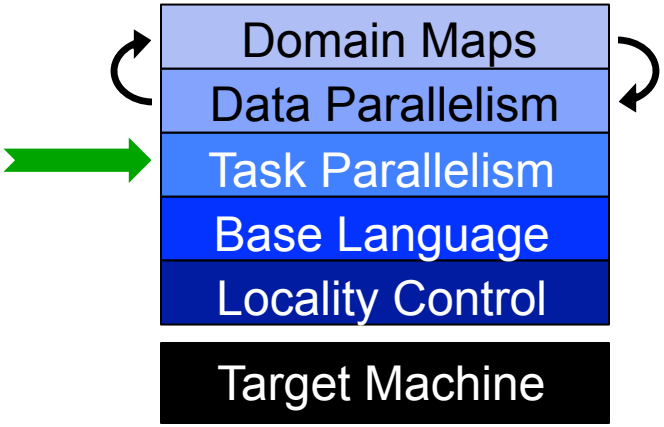
```
class Circle {
 var x, y: int;
 var r: real;
}
var c = new Circle(r=2.0);

proc Circle.area()
 return pi*r**2;
writeln(c.area());

class Oval: Circle {
 var r2: real;
}
proc Oval.area()
 return pi*r*r2;

var o: Circle = new Oval(r=1.0,r2=2.0);
writeln(o.area());
```

```
12.56
6.28
```

Other Base Language Features

- tuple types and values
- records
- modules
- unions
- enums
- interoperability features

Task Parallel Features



Tasks: discrete units of computation that can, and should, be executed in parallel.

Coforall Loops

```
coforall t in 0..#numTasks {
  writeln("Hello from task ", t, " of ", numTasks);
} // implicit join of the numTasks tasks here

writeln("All tasks done");
```

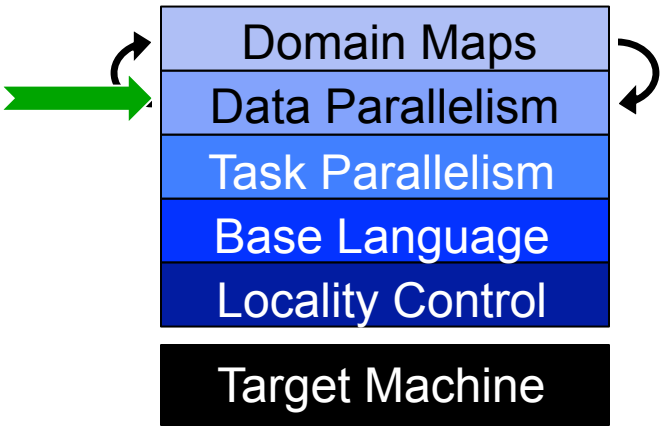
Sample output:

```
Hello from task 2 of 4
Hello from task 0 of 4
Hello from task 3 of 4
Hello from task 1 of 4
All tasks done
```

Other Task Parallel Features

- begin, cobegin
- synchronization blocks
- atomic and synchronization variables

Data Parallel Features



Forall Loops

```
forall a in 1..n do
  writeln("Here is an a: ", a);
```

Typically 1 ≤ #Tasks << #Iterations)

```
forall (a, i) in zip(A, 1..n) do
  a = i/10.0;
```

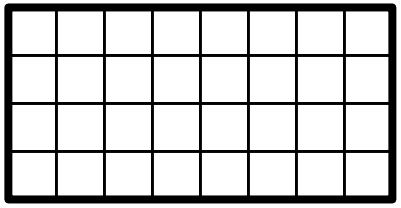
Forall-loops may be zippered, like for-loops
- Corresponding iterations will match up

Domains

Domain:

- First-class index set
- Used to declare and operate on arrays
- Drive iteration

```
config const m = 4, n = 8;

var D: domain(2) = {1..m, 1..n};
```

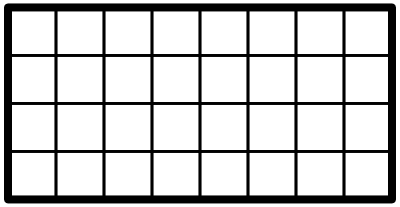


D

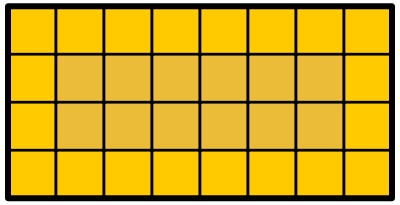
Arrays

```
config const m = 4, n = 8;

var D: domain(2) = {1..m, 1..n};

var A: [D] real;
var B: [D] string;
```

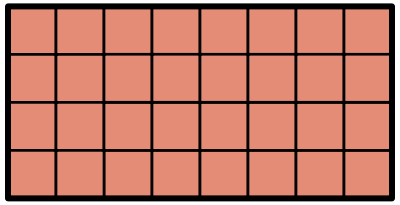
```
forall (i, j) in D {
  A(i, j) = i + j/10.0;
  B(i, j) = i + "," + j;
}
```



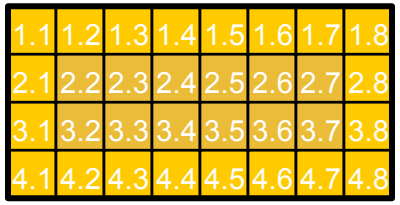
D



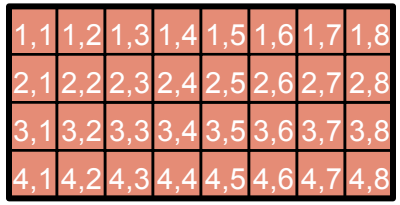
A



B

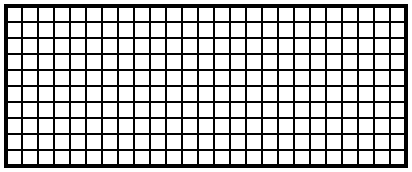


A

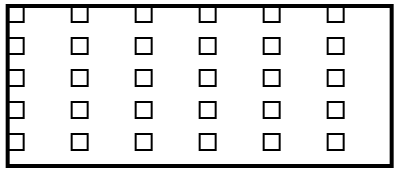


B

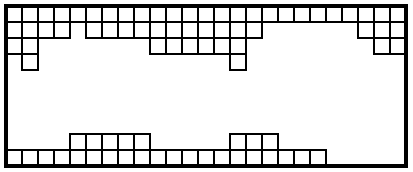
Chapel Domain Types



dense

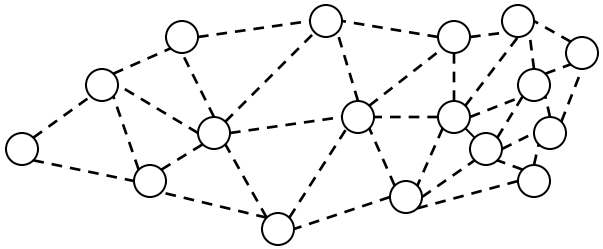


strided



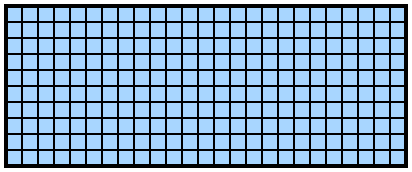
sparse

associative

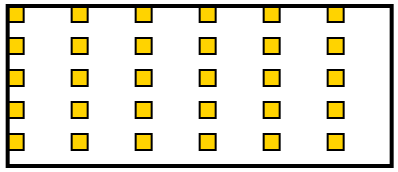


unstructured

Chapel Array Types



dense



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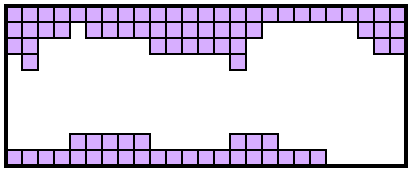
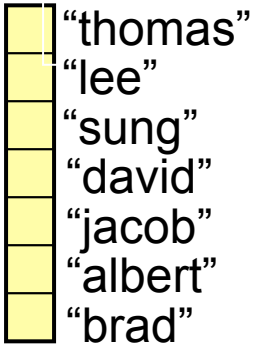
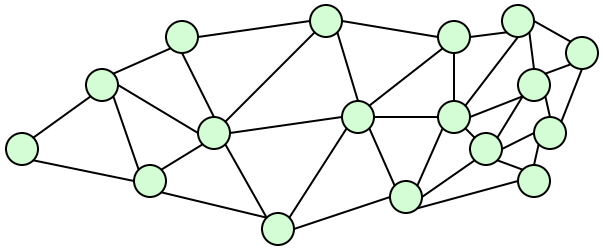


sparse



associative

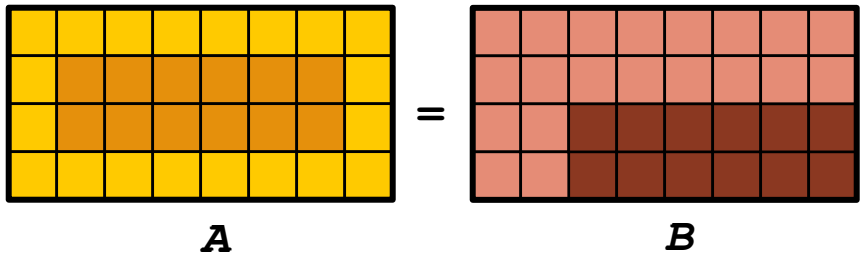


unstructured

Chapel Domain/Array Operations

- **Array Slicing; Domain Algebra**

```
var InnerD: subdomain(D) =
  {2..m-1, 2..n-1};
A[InnerD] = B[InnerD+(1,1)];
```



- **Promotion of Scalar Operators and Functions**

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

```
A = exp(B, C);
```

```
A = foo(B, C);
```

Promotion Semantics

Promoted functions/operators are defined in terms of zippered forall loops in Chapel. For example…

```
A = B;
```

⇒

```
forall (a,b) in zip(A,B) do
  a = b;
```

Whole-array operations are implemented element-wise.

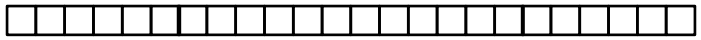
```
A = B + alpha * C;
```

⇒

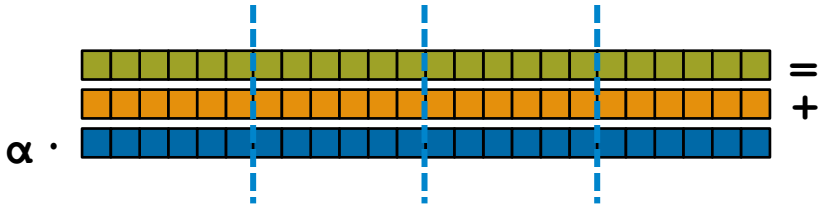
```
forall (a,b,c) in (A,B,C) do
  a = b + alpha * c;
```

Trivial Example: Chapel (multicore)

```
const ProblemDomain = {1..m};
```

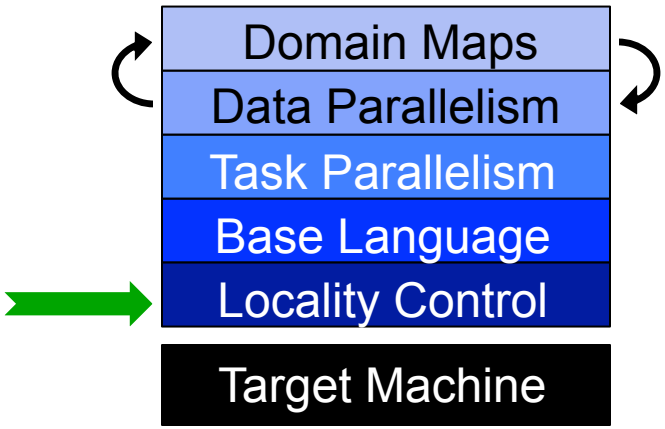


```
var A, B, C: [ProblemDomain] real;
```




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

Locality Control Features



Locale: abstract unit of target architecture that can run tasks and store variables.

Defining Locales

- Specify # of locales when running Chapel programs

```
% a.out --numLocales=8
```

- Chapel provides built-in locale variables

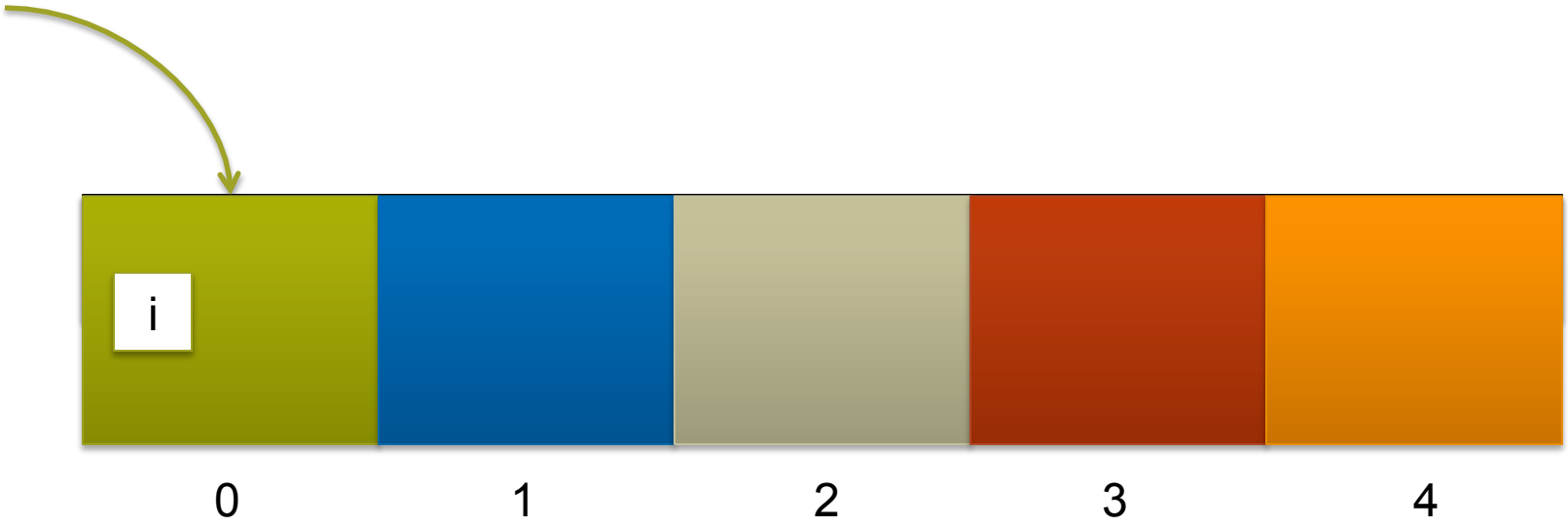
```
config const numLocales: int = …;
const Locales: [0..#numLocales] locale = …;
```

- User's `main()` begins executing on locale #0

Chapel: Scoping and Locality

```
% a.out --numLocales=5
```

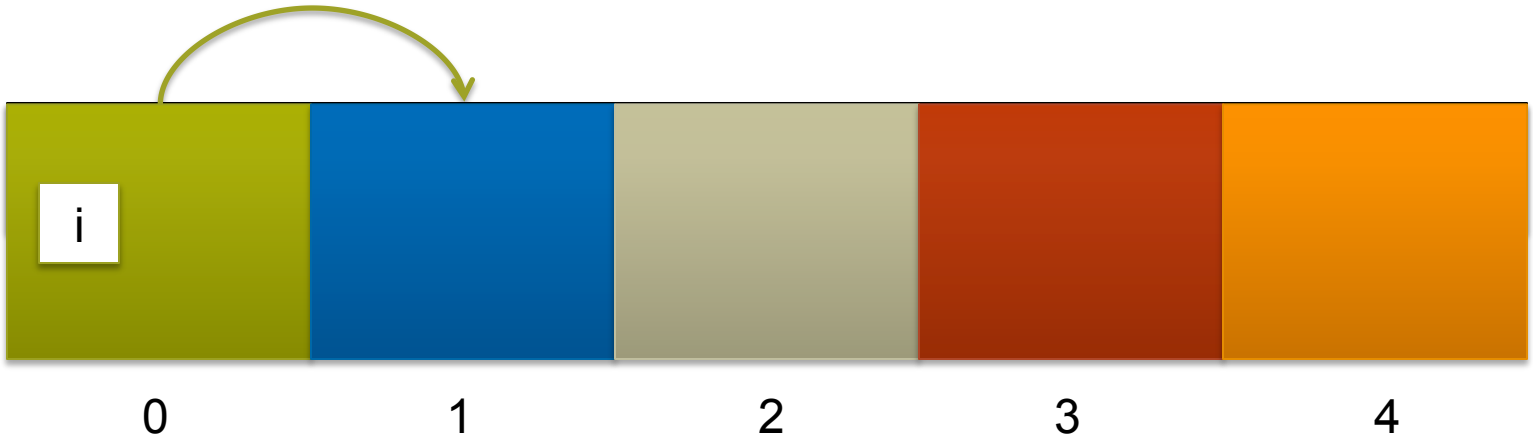
```
var i: int;
```



Chapel: Scoping and Locality

```
% a.out --numLocales=5
```

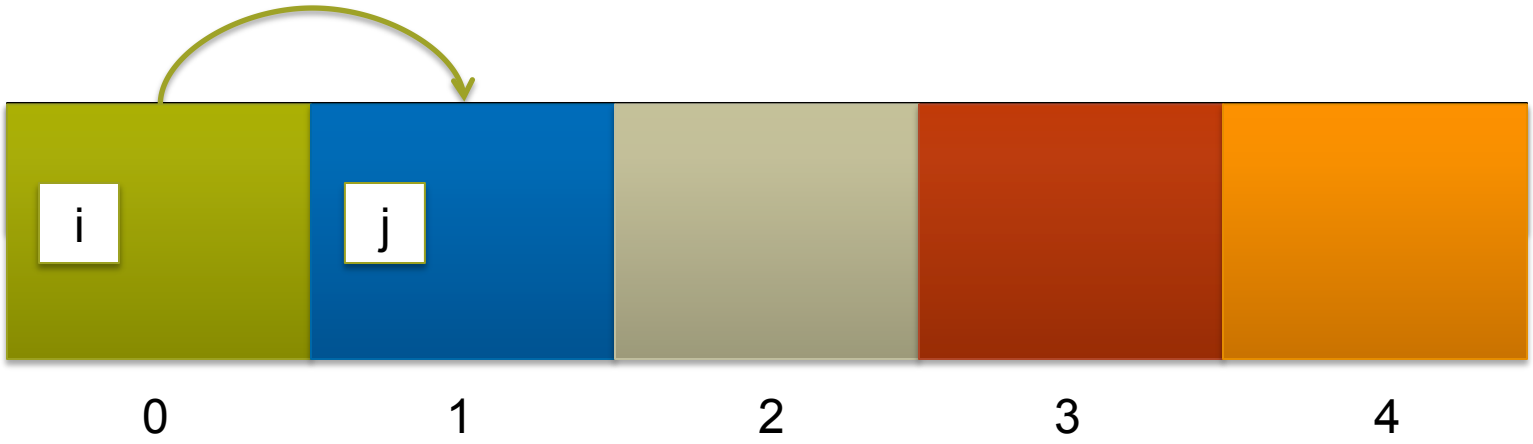
```
var i: int;
on Locales[1] {
```



Chapel: Scoping and Locality

```
% a.out --numLocales=5
```

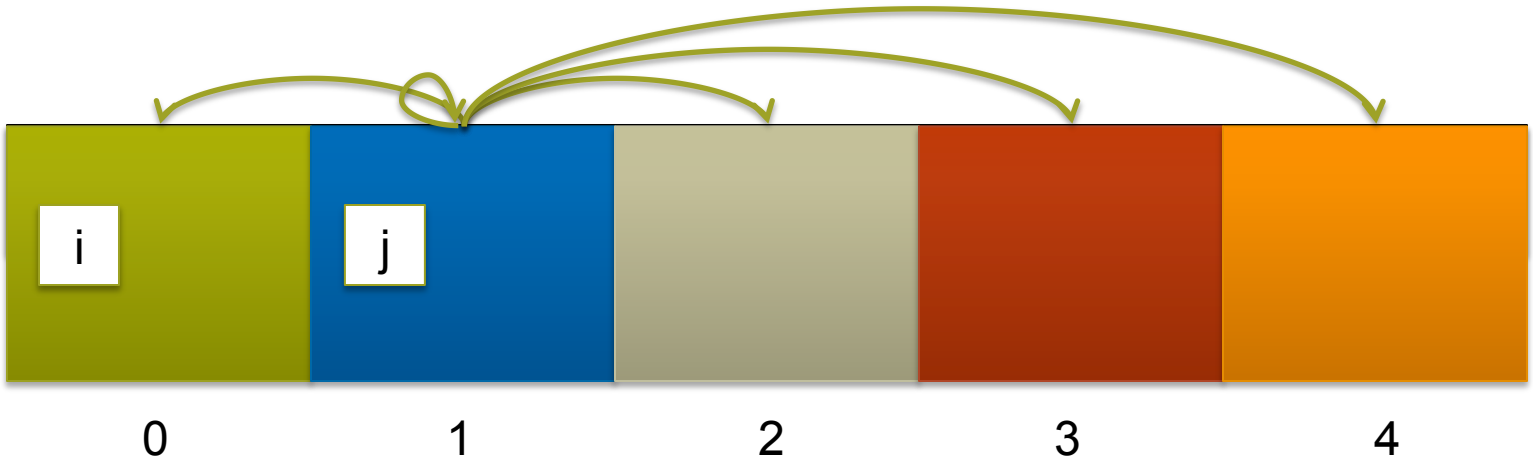
```
var i: int;
on Locales[1] {
  var j: int;
```



Chapel: Scoping and Locality

```
% a.out --numLocales=5
```

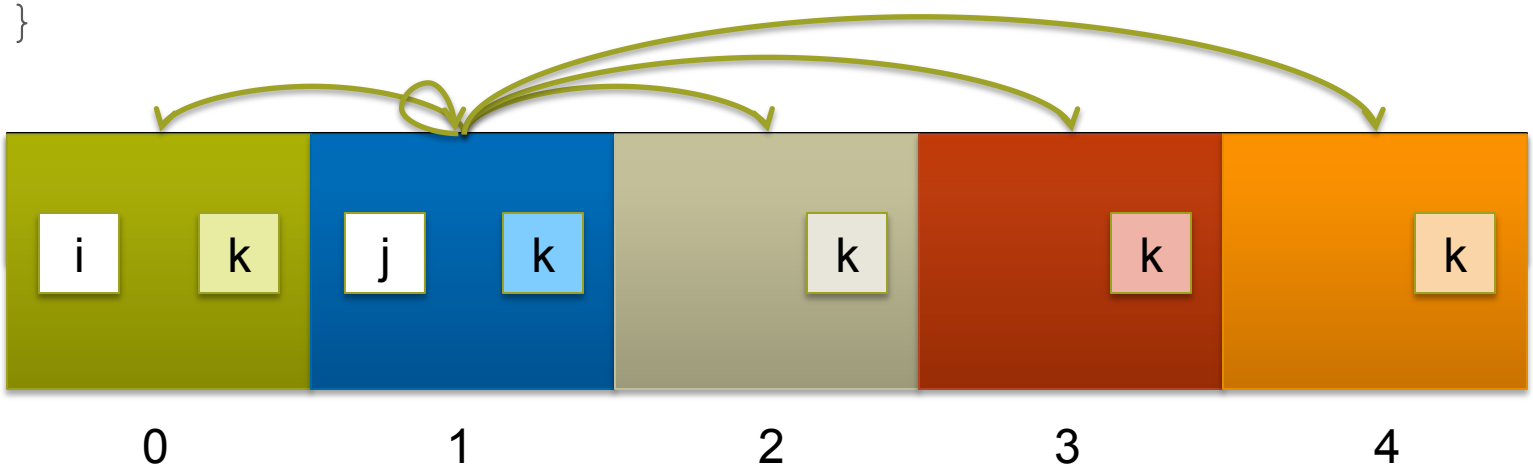
```
var i: int;
on Locales[1] {
  var j: int;
  coforall loc in Locales {
    on loc {
```



Chapel: Scoping and Locality

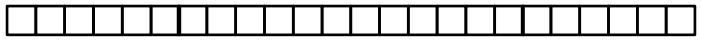
```
% a.out --numLocales=5
```

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

      // within this scope, i, j can be referenced;
      // the implementation manages the communication
    }
  }
}
```

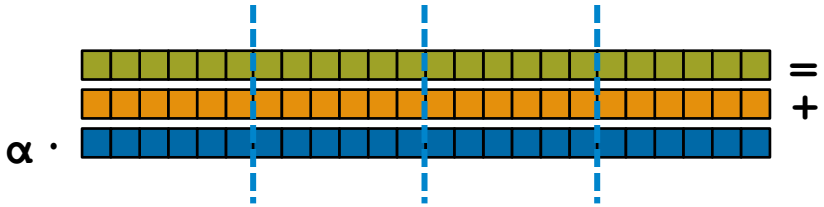


Trivial Example: Chapel (multicore)

```
const ProblemDomain = {1..m};
```

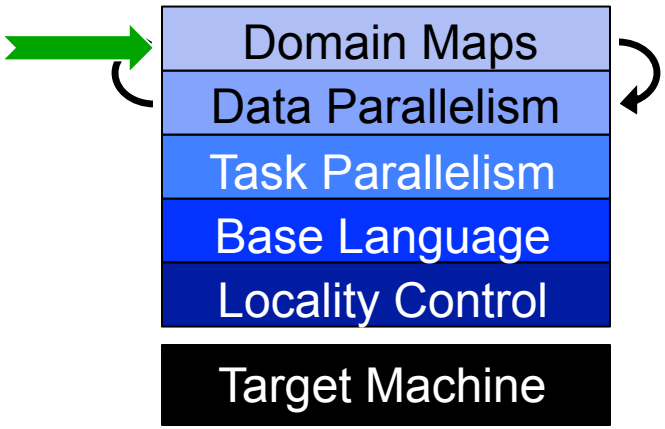


```
var A, B, C: [ProblemDomain] real;
```



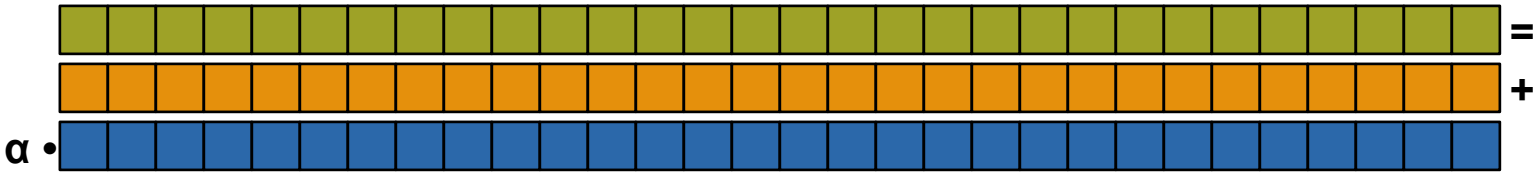

```
A = B + alpha * C;
```

Domain Map Features



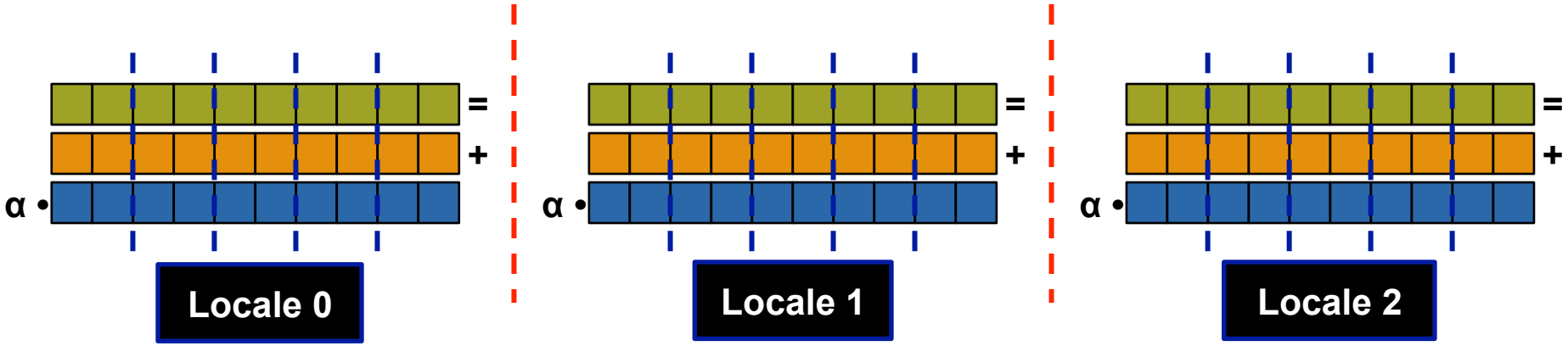
Domain Maps

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



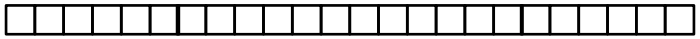

```
A = B + alpha * C;
```

…to the target locales' memory and processors:

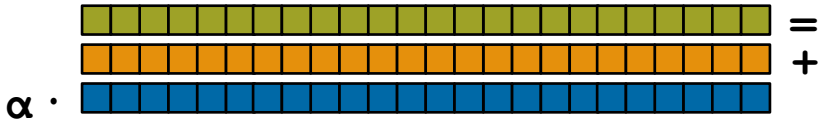


Trivial Example: Chapel

```
const ProblemDomain = {1..m};
```



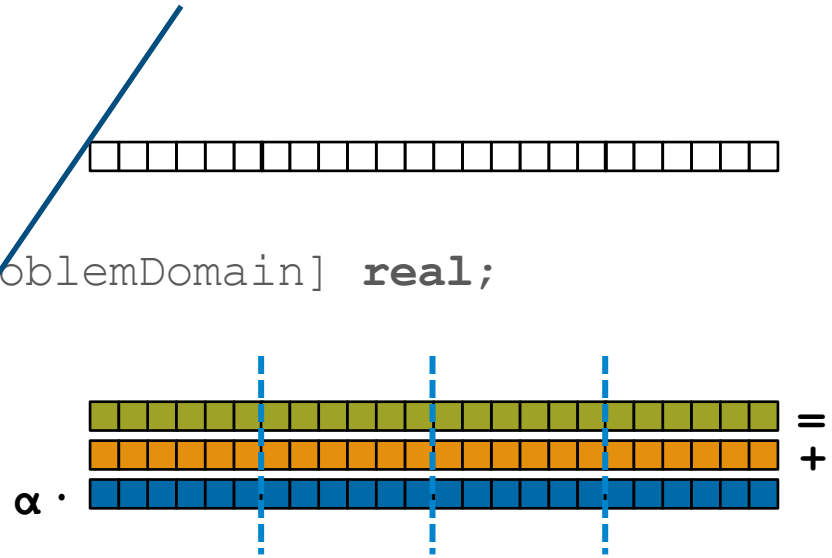
```
var A, B, C: [ProblemDomain] real;
```




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

Trivial Example: Chapel (multicore)

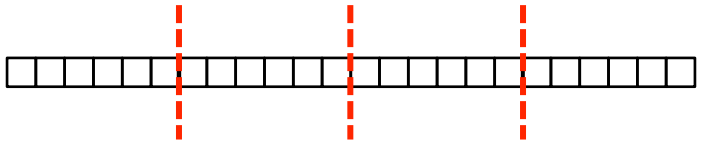
```
const ProblemDomain = {1..m};

var A, B, C: [ProblemDomain] real;

A = B + alpha * C;
```



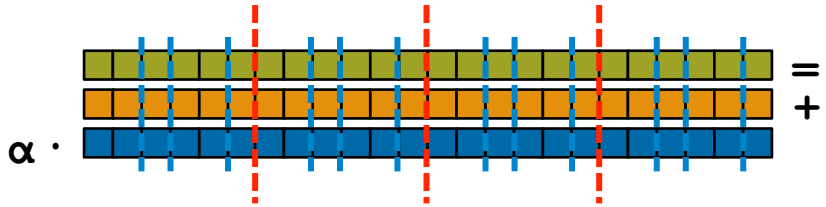
No domain map specified => use default layout
- current locale owns all indices and values
- computation will execute using local processors only

Trivial Example: Chapel (multilocale, blocked)

```
const ProblemDomain = {1..m}
                      dmapped Block({1..m});
```



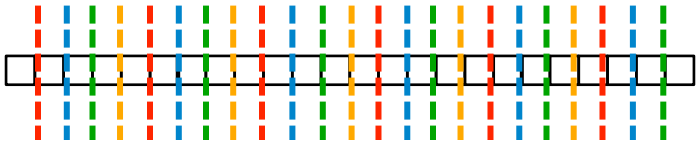
```
var A, B, C: [ProblemDomain] real;
```



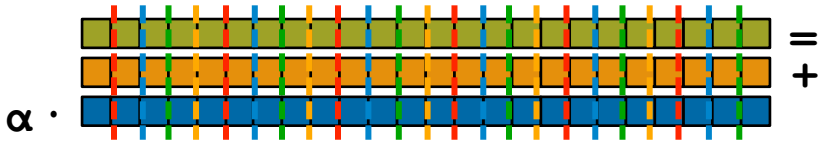

```
A = B + alpha * C;
```

Trivial Example: Chapel (multilocale, cyclic)

```
const ProblemDomain = {1..m}
                      dmapped Cyclic(startIdx=1);
```

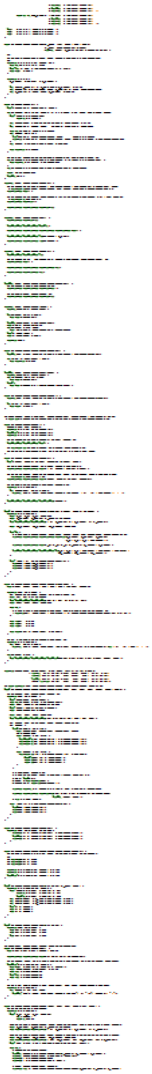


```
var A, B, C: [ProblemDomain] real;
```

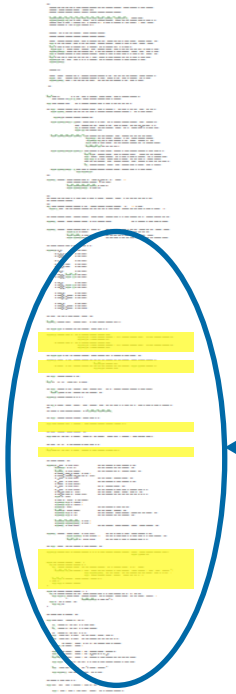


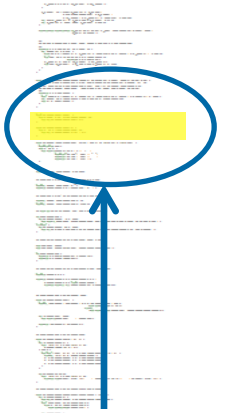

```
A = B + alpha * C;
```

LULESH in Chapel



LULESH in Chapel





This is all of the representation dependent code. It specifies:

- data structure choices
  - structured vs. unstructured mesh
  - local vs. distributed data
  - sparse vs. dense materials arrays
- their corresponding iterators

Implementation Status -- Version 1.9.0 (Apr 2014)

Overall Status:

- Most features work at a functional level
- Many performance optimizations remain

This is a good time to:

- Try out the language and compiler
- Use Chapel for non-performance-critical projects
- Give us feedback to improve Chapel
- Use Chapel for parallel programming education

Chapel: the next five years

- Harden Prototype to Production-grade
- Target more complex/modern compute node types
- Continue to grow the user and developer communities

For More Information: Online Resources

Chapel project page: http://chapel.cray.com

Chapel SourceForge page: https://sourceforge.net/projects/chapel/

Mailing Aliases:

- chapel_info@cray.com: contact the team at Cray
- chapel-announce@lists.sourceforge.net: announcement list
- chapel-users@lists.sourceforge.net: user-oriented discussion list
- chapel-developers@lists.sourceforge.net: developer discussion
- chapel-education@lists.sourceforge.net: educator discussion
- chapel-bugs@lists.sourceforge.net: public bug forum

For More Information: Suggested Reading

Overview Papers:

- *A Brief Overview of Chapel*, Chamberlain (pre-print of a chapter for *A Brief Overview of Parallel Programming Models*, edited by Pavan Balaji, to be published by MIT Press in 2014).
  - *a more detailed overview of Chapel's history, motivating themes, features*

- *The State of the Chapel Union* [slides], Chamberlain, Choi, Dumler, Hildebrandt, Iten, Litvinov, Titus. CUG 2013, May 2013.
  - *a high-level overview of the project summarizing the HPCS period*

Chapel…

…is a collaborative effort — join us!