THE SUPERCOMPUTER COMPANY

SC11 Seattle, WA
Connecting communities through HPC

Chapel: Domain Maps

(Layouts and Distributions)

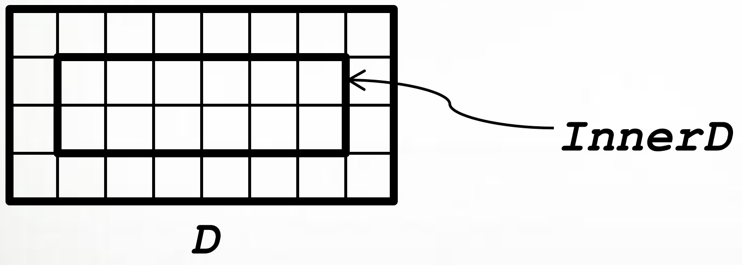
"Hello World" in Chapel: a Domain-Map Version

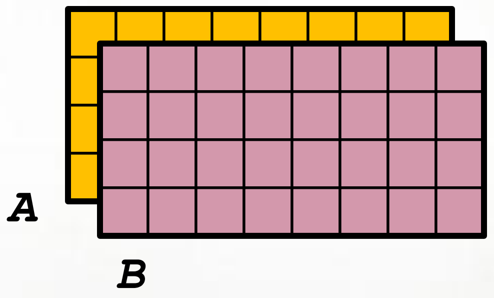
- Multi-locale Data Parallel Hello World

```
config const numIters = 100000;
const WorkSpace = [1..numIters] dmapped Block(…);

forall i in WorkSpace do
  writeln("Hello, world! ",
          "from iteration ", i, " of ", numIters,
          " on locale ", here.id, " of ", numLocales);
```

Review: Data Parallelism

- Domains are first-class index sets
  - Specify the size and shape of arrays
  - Support iteration, array operations, etc.

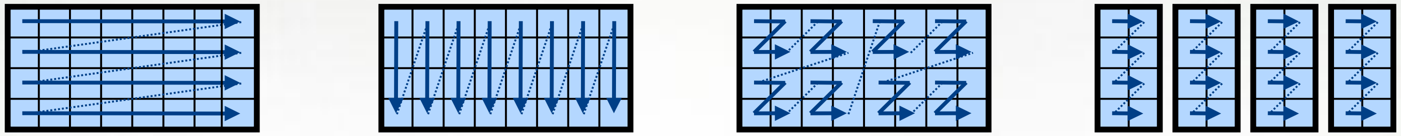




Data Parallelism: Implementation Qs

Q1: How are arrays laid out in memory?

- Are regular arrays laid out in row- or column-major order? Or…?

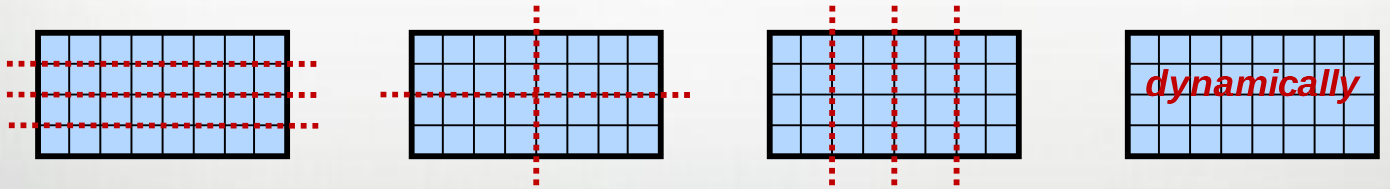


…?

- What data structure is used to store sparse arrays? (COO, CSR, …?)

Q2: How are data parallel operators implemented?

- How many tasks?
- How is the iteration space divided between the tasks?



…?

Data Parallelism: Implementation Qs

Q3: How are arrays distributed between locales?

- Completely local to one locale? Or distributed?
- If distributed… In a blocked manner? cyclically? block-cyclically? recursively bisected? dynamically rebalanced? …?

Q4: What architectural features will be used?

- Can/Will the computation be executed using CPUs? GPUs? both?
- What memory type(s) is the array stored in? CPU? GPU? texture? …?

A1: In Chapel, any of these could be the correct answer

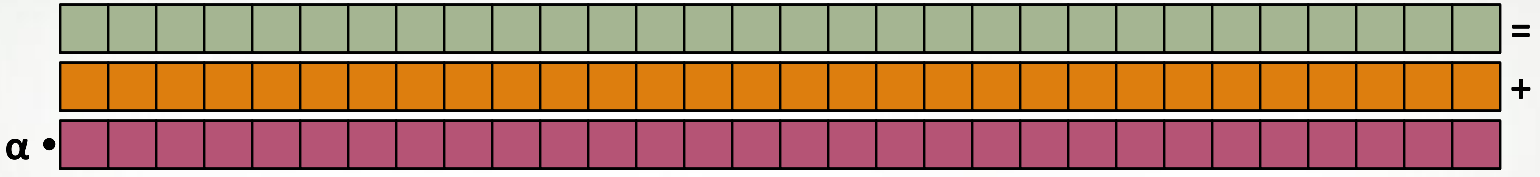
A2: Chapel's *domain maps* are designed to give the user full control over such decisions

Outline

- Data Parallelism Revisited
- Domain Maps
  - Layouts
  - Distributions

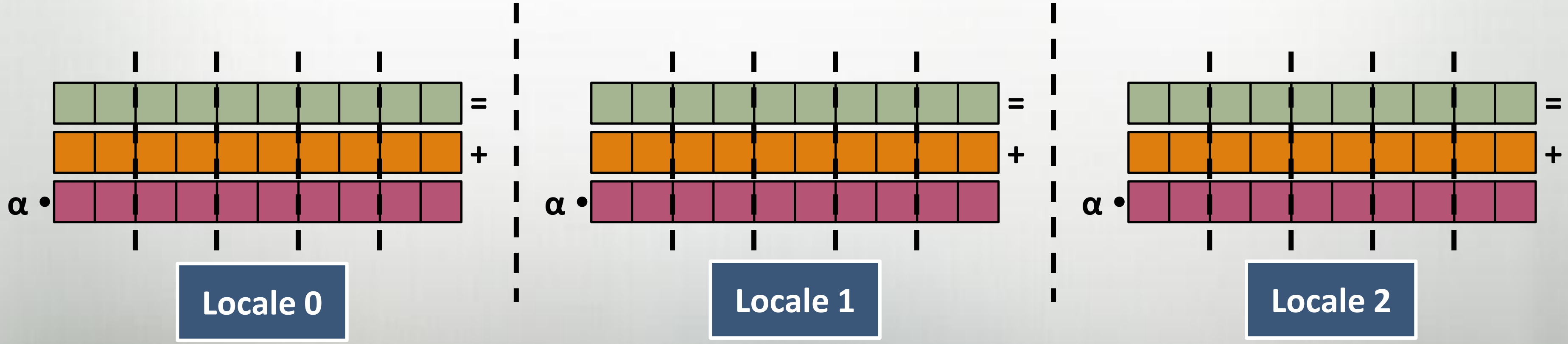
Domain Maps

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:



Domain Maps

Domain Maps: "recipes for implementing parallel/ distributed arrays and domains"

They define data storage:

- Mapping of domain indices and array elements to locales
- Layout of arrays and index sets in each locale's memory

…as well as operations:

- random access, iteration, slicing, reindexing, rank change, …
- the Chapel compiler generates calls to these methods to implement the user's array operations

Domain Maps: Layouts and Distributions

Domain Maps fall into two major categories:

layouts: target a single shared memory segment

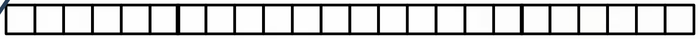
- (that is, a desktop machine or multicore node)
- **examples:** row- and column-major order, tilings, compressed sparse row

distributions: target distinct memory segments

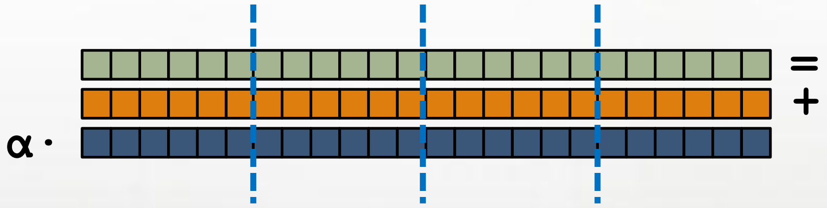
- (that is a distributed memory cluster or supercomputer)
- **examples:** Block, Cyclic, Block-Cyclic, Recursive Bisection, …

STREAM Triad: Chapel (multicore)

```
const ProblemSpace = [1..m];
```



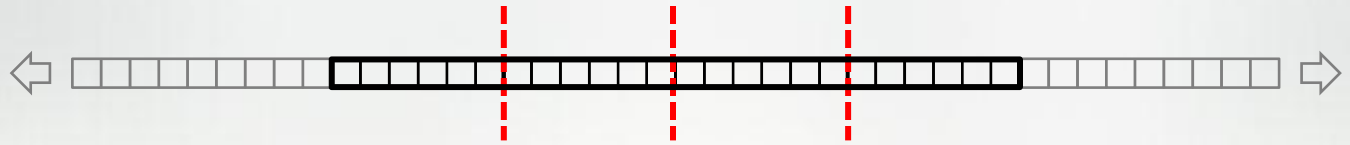
```
var A, B, C: [ProblemSpace] real;
```



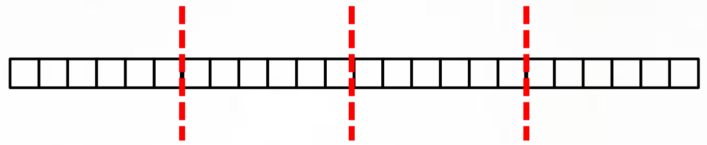
```
A = B + alpha * C;
```

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

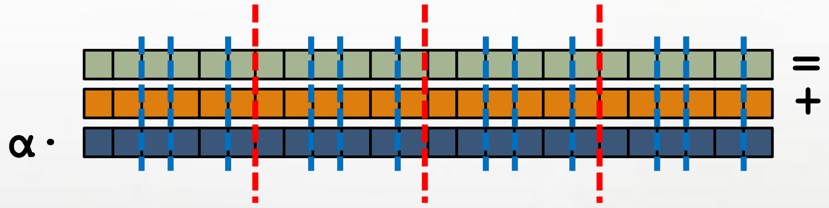
STREAM Triad: Chapel (multinode, blocked)



```
const ProblemSpace = [1..m]
                         dmapped Block(boundingBox=[1..m]);
```

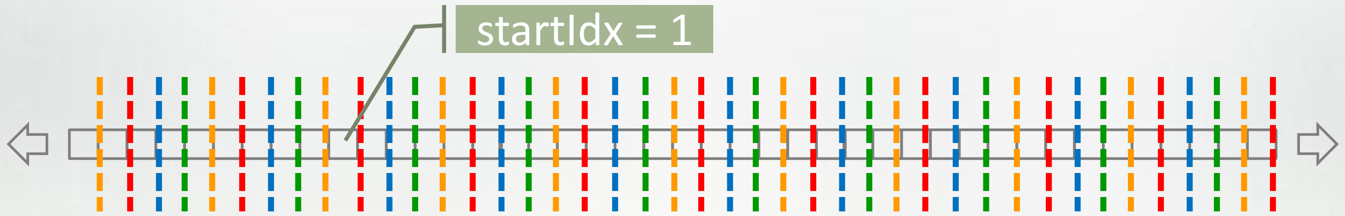


```
var A, B, C: [ProblemSpace] real;
```

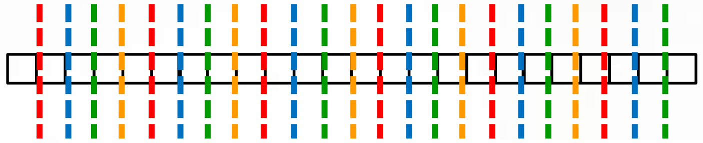


```
A = B + alpha * C;
```

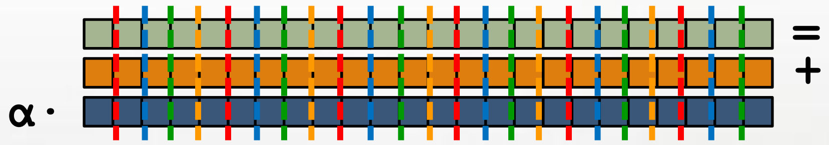
STREAM Triad: Chapel (multinode, cyclic)



```
const ProblemSpace = [1..m]
                              dmapped Cyclic(startIdx=1);
```



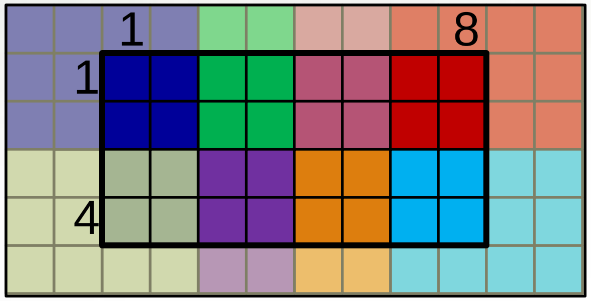
```
var A, B, C: [ProblemSpace] real;
```



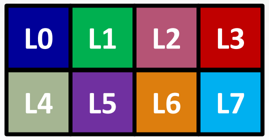
```
A = B + alpha * C;
```

Some Standard Distributions: Block and Cyclic

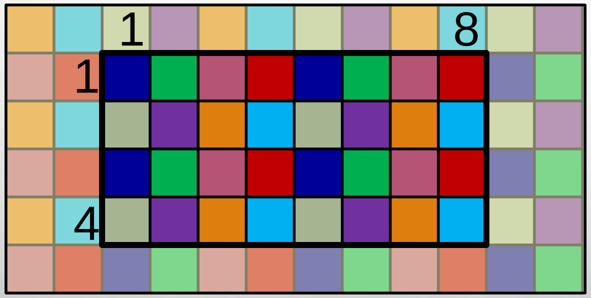
```
var Dom: domain(2) dmapped Block(boundingBox=[1..4, 1..8])
       = [1..4, 1..8];
```



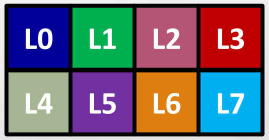
distributed to



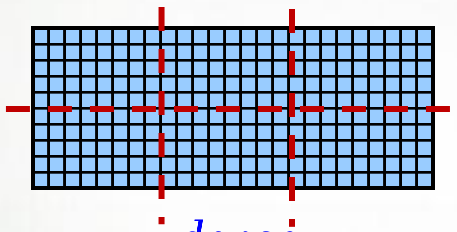
```
var Dom: domain(2) dmapped Cyclic(startIdx=(1,1))
       = [1..4, 1..8];
```

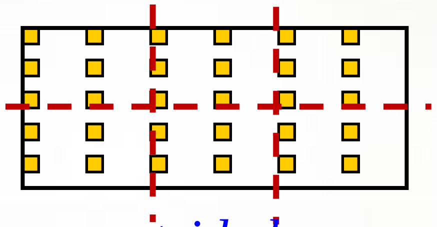


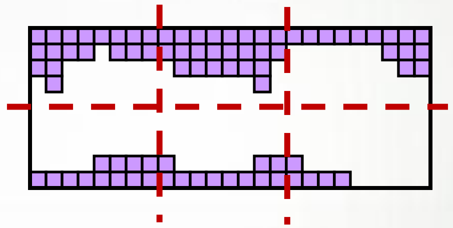
distributed to

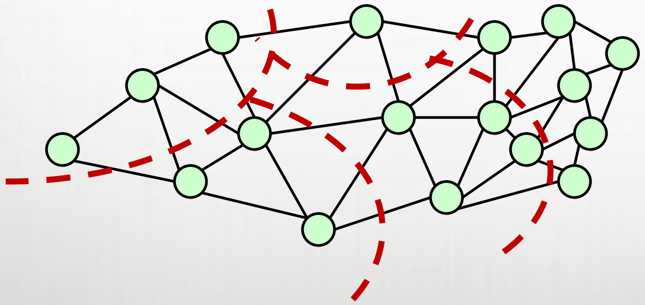


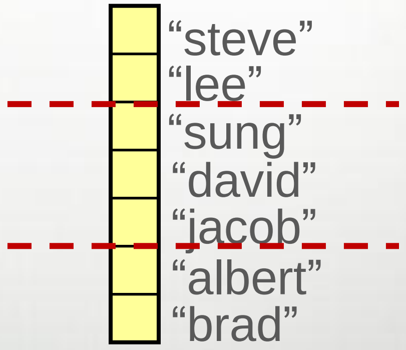
All Domain Types Support Domain Maps


dense


strided


sparse


unstructured



associative

Chapel's Domain Map Philosophy

1. Chapel provides a library of standard domain maps
   - to support common array implementations effortlessly
2. Advanced users can write their own domain maps in Chapel
   - to cope with shortcomings in our standard library
3. Chapel's standard layouts and distributions will be written using the same user-defined domain map framework
   - to avoid a performance cliff between "built-in" and user-defined domain maps
4. Domain maps should only affect implementation and performance, not semantics
   - to support switching between domain maps effortlessly

Declaring a Distributed Domain

- Domain types and literals may be domain mapped:

```
var Dom: domain(…) dmapped myDMap(…)
           = […] dmapped myDMap(…);
```

- In practice, this tends to be a great place to rely on type inference to avoid repetition:

```
var Dom = […] dmapped myDMap(…);
```

Declaring Domain Maps

- Syntax

```
dmap-type:
  dmap(dmap-class(…))
dmap-value:
  new dmap(new dmap-class(…))
```

- Semantics
  - Domain maps can be declared independently of a domain
  - Useful for declaring multiple domains using the same map
- Examples

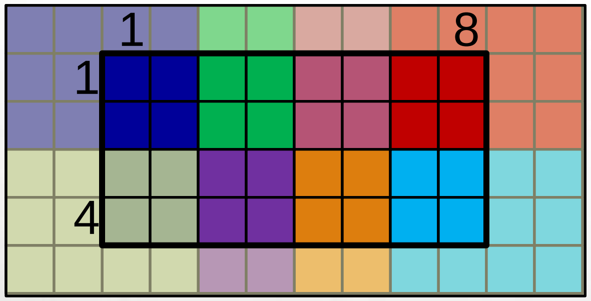
```
use myDMapMod;
var DMap: dmap(myDMap(…)) = new dmap(new myDMap(…));

var Dom: domain(…) dmapped DMap;
var A: [Dom] real;
```

Outline

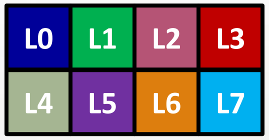
- Data Parallelism Revisited
- Domain Maps
- Chapel Standard Layouts and Distributions
  - Block
  - Cyclic

The Block class constructor

```
proc Block(boundingBox: domain,
           targetLocales: [] locale = Locales,
           dataParTasksPerLocale = ...,
           dataParIgnoreRunningTasks = ...,
           dataParMinGranularity = ...,
           param rank = boundingBox.rank,
           type idxType = boundingBox.dim(1).eltType)
```

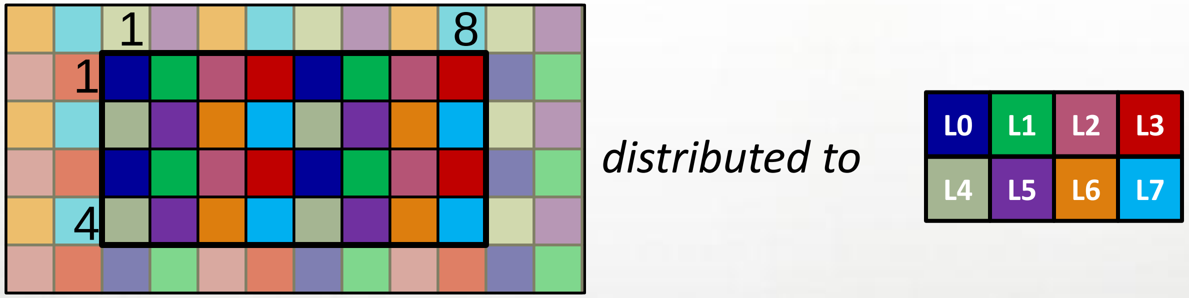


distributed to



The Cyclic class constructor

```
proc Cyclic(startIdx,
            targetLocales: [] locale = Locales,
            dataParTasksPerLocale = ...,
            dataParIgnoreRunningTasks = ...,
            dataParMinGranularity = ...,
            param rank: int = infered from startIdx,
            type idxType = infered from startIdx)
```



"Hello World" in Chapel: a Domain-Map Version

- Multi-locale Data Parallel Hello World

```
config const numIters = 100000;
const WorkSpace = [1..numIters] dmapped Block(…);

forall i in WorkSpace do
  writeln("Hello, world! ",
          "from iteration ", i, " of ", numIters,
          " on locale ", here.id, " of ", numLocales);
```

For More Information on Domain Maps

HotPAR'10: *User-Defined Distributions and Layouts in Chapel: Philosophy and Framework,* Chamberlain, Deitz, Iten, Choi; June 2010

CUG 2011: *Authoring User-Defined Domain Maps in Chapel,* Chamberlain, Choi, Deitz, Iten, Litvinov; May 2011

Chapel release:

- Technical notes detailing domain map interface for programmers:

  $CHPL_HOME/doc/technotes/README.dsi
- Current domain maps:

  $CHPL_HOME/modules/dists/*.chpl

  layouts/*.chpl

  internal/Default*.chpl

Domain Maps: Status

- Full-featured Block, Cyclic, Replicated distributions
- COO and CSR Sparse layouts supported
- Quadratic probing Associative layout supported
- Block-Cyclic, Dimensional, Associative distributions underway
- User-defined domain map interface still evolving
- Memory currently leaked for distributed arrays

Future Directions

- Advanced uses of domain maps:
  - GPU programming
  - Dynamic load balancing
  - Resilient computation
  - *in situ* interoperability
  - Out-of-core computations
- Improved syntax for declared domain maps

Questions?

- Data Parallelism Revisited
- Domain maps
  - Layouts
  - Distributions
- The Chapel Standard Distributions
  - Block Distribution
  - Cyclic Distribution
- User-defined Domain Maps